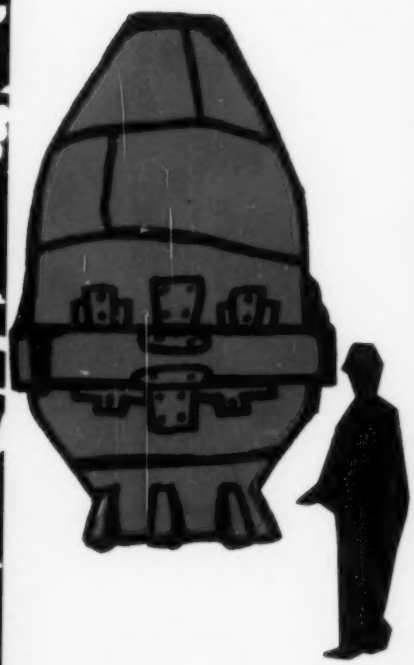
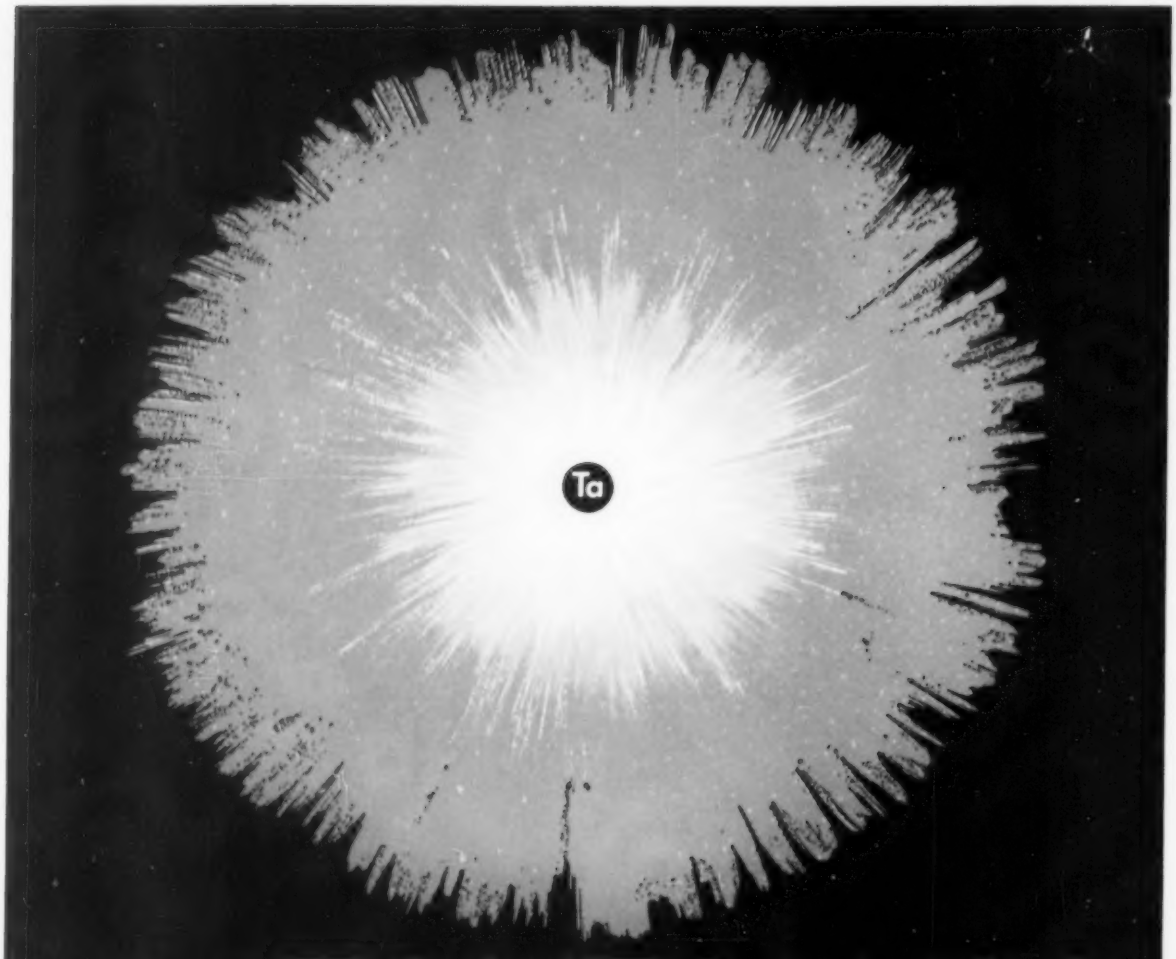
JOURNAL OF

METALS

OCTOBER 1957

IN TWO SECTIONS—SECTION ONE





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JOURNAL OF

METALS

VOL 9, NO. 10

OCTOBER 1957

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1—Magazine 2—Transactions Section

COVER

Cover designer Naomi Lazard has chosen pilot plants as her theme for this month's cover. Two articles dealing with the principles and execution and design of pilot plants are presented on pages 1353 and 1359. Also presented in this issue on page 1367 is part 3, the concluding part, of *Blast Furnace U. S. A.*

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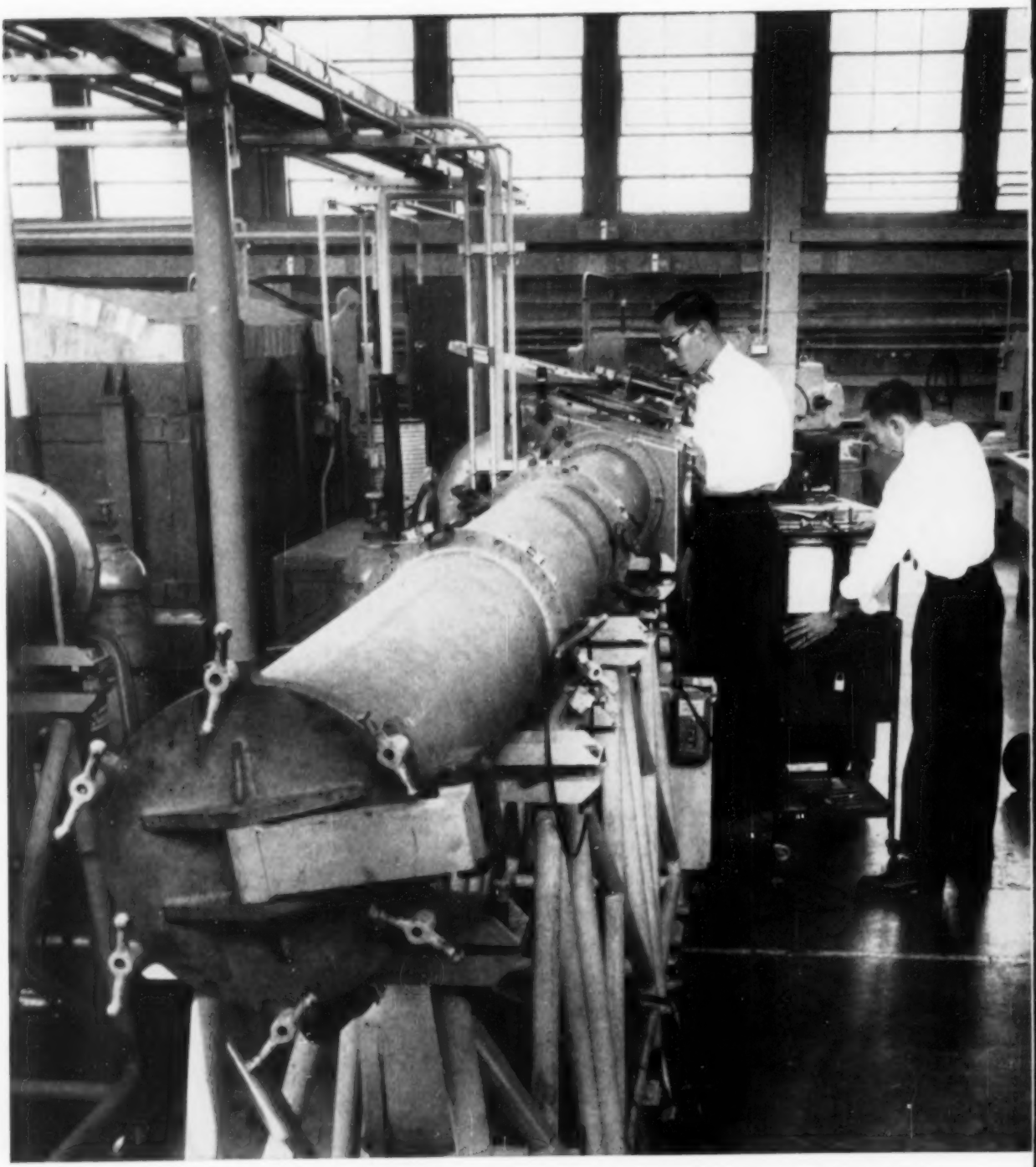

James G. Goodwin (Penn State '51), Senior Engineer in the Special Materials Section of Bettis Atomic Power Division, on left, examines a completed weld made on the central thimble tube. Mr. Goodwin directed the program to develop the proper process for fabricating Zircaloy-2 Pressure Vessel for irradiation studies. Richard M. Lieberman (Lafayette '52), Associate Engineer in the Loop Design and Operation Group, checks voltage and amperage records of the welding performance.

METALLURGICAL PROCESS DEVELOPMENT

Fabrication of Zircaloy-2 Pressure Vessel for Irradiation Studies

To test fuel elements being developed for a pressurized water reactor, engineers at Bettis Atomic Power Division have constructed an in-pile loop capable of sustaining fuel element temperatures and heat output conditions which approximate and even exceed actual reactor operating conditions. Stainless steel had been used for such loops. However, since increased neutron efficiency was desired, consideration was given to materials with lower neutron cross sections. A zirconium alloy (Zircaloy-2) was selected as an alternate material because, in addition to low thermal-neutron absorption, it has excellent corrosion resistance to high temperature water.

After Richard M. Lieberman, Associate Engineer in the Loop Design and Operation Group, designed the tube, James G. Goodwin, Senior Engineer in the Special Materials Section, directed a program to develop the proper process for fabricating the apparatus which was to be capable of withstanding 2500 psi internal pressure at 650°F. The vessel, constructed from a tubular extrusion (4.520 in. OD x 3.136 in. ID x 22 ft ¾ in. long) was one of the largest single items ever manufactured from Zircaloy-2 and involved problems in four major areas: extrusion, machining, welding, and corrosion resistance.

Several problems were anticipated in extruding the tube. First, the severe galling tendency of Zircaloy created lubrication problems particularly on the tube ID. The long extrusion billet and the relatively small ID of the tube introduced problems concerned with the strength of a long, thin mandrel under the severe tensile forces of extrusion. Because of the small amount of metal cleanup allowed for the ID due to mandrel diameter limitations, good concentricity of the extruded tube was mandatory.

In order to straighten the 22 ft tube for accurate and precise machining, cold deflections of up to 7 in. were required.

The problem of producing sound welds included the need for complete penetration at the weld joints and rotation of the massive unit at a uniform speed during filler metal additions. Since contamination with air during welding would have produced brittle and corrodible welds, the tube had to be welded in an inert atmosphere.

Closeup of closure for Zircaloy in-pile tube.

To insure corrosion resistance of the finished tube, a layer of disturbed metal formed on the Zircaloy during machining had to be removed by etching. The configuration of the tube created difficulties in maintaining dimensional tolerances during the process and in removing all traces of corrosive acid.

The completed tube was installed in March, 1957 and has been operating continually in a large test reactor. During this development project, close technical cooperation was maintained throughout by Bettis and the test reactor personnel on design, fabrication and evaluation of the tube.

This is only one example of the challenging work conducted here. We welcome inquiries from metallurgists interested in the excellent careers offered by the new and growing nuclear power industry. Please send your résumé to: Mr. M. J. Downey, Bettis Atomic Power Division, Westinghouse Electric Corporation, P.O. Box 1468, Department A211, Pittsburgh 30, Pennsylvania.

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Metallurgist, with a few years experience, for gravity separation laboratory. Salary, open. Location, Florida. W5309(b).

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Development Metallurgists, B.S. in metallurgical engineering, with three to five years industrial experience, to investigate manufacturing prob-

(*Continued on page 1322*)

Additional classified advertising appears on pages 1318, 1319, 1322, 1324, and 1325.

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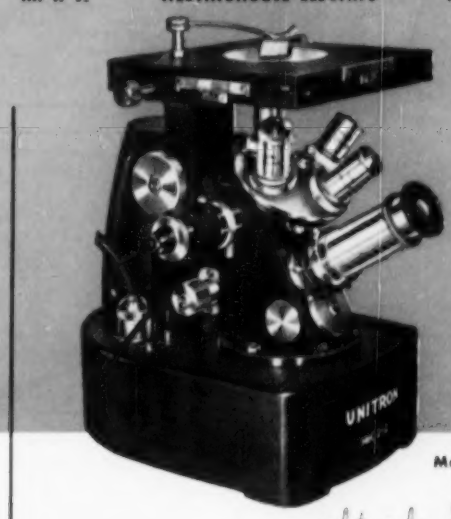

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(Continued from page 1320)

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Directory of Consulting Engineers and Architects, published by the San Francisco Chamber of Commerce, Industrial Dept., 333 Pine St., San Francisco 4, Calif., 24 pp., $1.00, 1957.—Firm names, principals, bank references, educational and professional qualifications, nature and scope of services, and principal accomplishments of 72 engineering firms and 45 architectural firms are included in the directory.

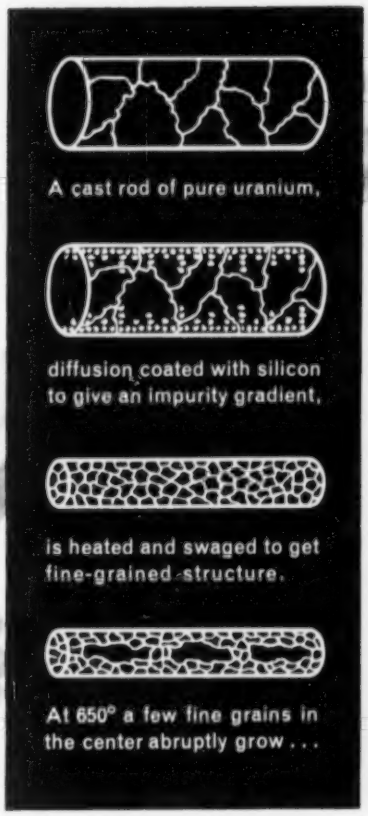
Engineering Economics and Ethics for Professional Engineers' License, John D. Constance, published by *John D. Constance*, 625 Hudson Terrace, Cliffside Park, N. J., $2.50, 1957.—The subject matter covers bond issues, bond valuation, debt amortization, property valuation, cost analysis, etc.

Industrial Organization and Management, by Ralph C. Davis, *Harper and Brothers*, 953 pp., $8.25, 1957.—Intended for industrial executives as well as for students of management, this book emphasizes fundamental objectives, policies, and methods of approach to the solution of business problems. The numerous examples of management practice have been taken from a variety of manufacturing companies. •

United States Government Organization Manual, published by the Office of Information, *General Services Administration*, Supt. of Documents, Government Printing Office, Washington 25, D. C., 778 pp., $1.50, 1957.—The manual lists 4100 key officials of the Federal Government. The publication also contains some 40 charts showing the organization of Congress, the executive departments, and the large independent agencies.

Metal Statistics—1957, published by the *American Metal Market*, 18 Cliff St., New York 38, N. Y., 856 pp., $3.50, 1957.—The *little red book*, as

(Continued on page 1326)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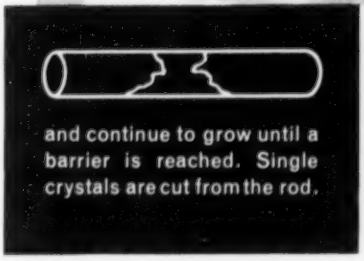

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Books

(Continued from page 1324)

it is known in the metal industries, contains over 400 statistical tables covering production, consumption, prices, and other data on ferrous and nonferrous metals.

Techniques of Plant Maintenance and Engineering—1957, published by *Clapp and Poliak Inc.*, 341 Madison Ave., New York 17, N. Y., 273 pp., $10.00, 1957.—The book covers the maintenance problems of metal-working plants, chemical plants, steel mills, metal fabricating plants, foundries, and many more such industries. Also included are 46 charts, diagrams, tables, and other illustrations.

Engineering Analysis, A Survey of Numerical Procedures, by Stephen H. Crandall, *McGraw-Hill Book Co. Inc.*, 417 pp., $9.50, 1957.—Three broad classifications of problems are recognized: equilibrium, eigenvalue, and propagation. Three items frequently omitted in engineering courses are developed: matrix notation, the calculus of variations, and the theory of characteristics of partial differential equations. •

Symposium on pH Measurement, published by the *American Society for Testing Materials*, 1916 Race St., Philadelphia 3, Pa., 104 pp., $2.50, 1957.—The symposium is of value not only to the theorist, analytical, and physical chemist, but also to the practicing process and control engineer. Covering such developments as nonaqueous solutions and refined methods of instrumentation, the symposium considers not only the advances in themselves but also the problems created by these developments. The volume is well illustrated and contains several extensive bibliographies. •

The Detroit Industry Engineering Committee, ECPD, is offering six booklets available from the *Engineering Society of Detroit*, 100 Farnsworth Ave., Detroit 2, Mich., at $2.50 per set. The booklets cover general introductory material, orientation and training in industry, appraisal and counseling on performance, continued education, reading list for engineers, and professional identification.

The Defect Solid State, by T. J. Gray and others, *Interscience Publishers Inc.*, 250 Fifth Ave., New York 1, N. Y., 511 pp., $11.00, 1957.—A collection of papers aimed at focusing attention on the relationship between the defect nature of solids and the various physical and chemical properties they exhibit. The papers, almost all with extensive lists of references, deal with semi-

(Continued on page 1328)

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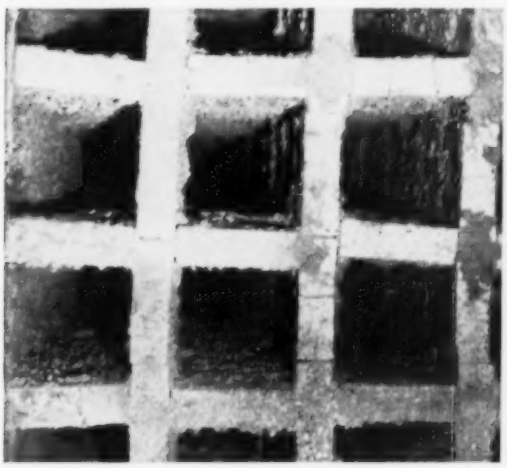
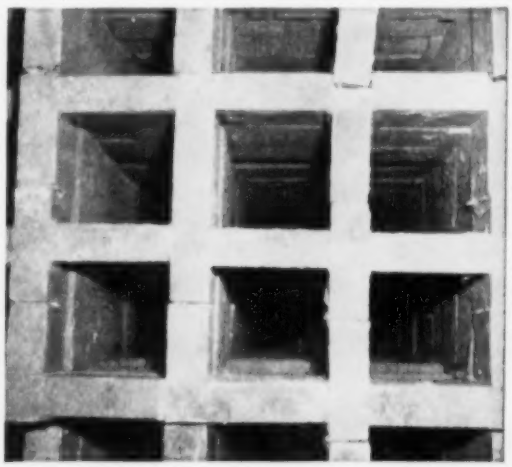
provide unusual advantages for open hearth steel furnaces



After two campaigns—378 heats—Forsterite L Open Hearth Checkers appeared as shown above. The friable character of the slight dust build-up is apparent.



Ready to go back into service. Cleaning is quickly and easily accomplished because Forsterite L Checkers resist slagging, spalling and clogging.

With the rapidly increasing use of basic brick checkers for open hearth steel furnaces, many of the various kinds have been in service for careful comparisons. Among the various classes of basic brick used in this application, FORSTERITE L, the magnesium-silicate refractory, shows unusual merit.

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FORSTERITE L checkers do not shrink or subside in soaking heats and higher preheat temperatures of the air are feasible. They are highly resistant to slagging and withstand the temperature changes involved without spalling. Because of the excellent stability of mineral composition under the prevailing regenerator conditions, FORSTERITE L brick do not permanently increase in volume nor become weak and friable.

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The inherent properties of the mineral forsterite account for the higher heat capacity of FORSTERITE L brand, than that of alumina-silica refractories. The heat capacity of a checker setting of a given size thus is greatly increased.

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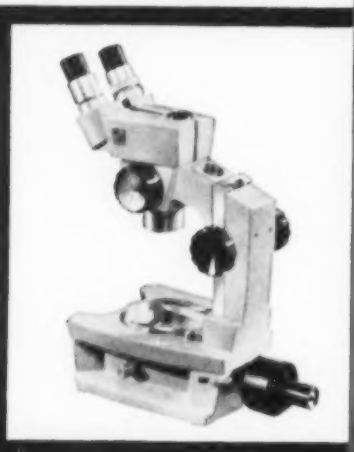

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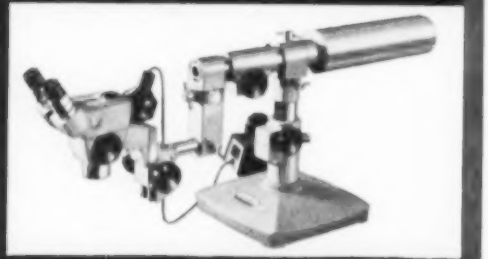

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Books

(Continued from page 1326)

conductivity, corrosion processes, magnetic properties of solids, defect structure and catalysis, dielectric materials, phase equilibria, intermetallic compounds, and experimental techniques. One paper is a summary of present knowledge and review of the literature on ceramic materials for high-temperature service.

Manufacturing Processes, Myron L. Begeman, *John Wiley & Sons Inc.*, 4th ed., 612 pp., $8.00, 1957.—This book presents a comprehensive survey of the technical fundamentals of important manufacturing processes involving engineering materials. New topics discussed are electrospark and ultrasonic machining, chem-milling, and automation. •

Die Verhuttung von Aluminiumschrott Kurt Schneider, 2nd ed., *Metall-Verlag GMBH*, Berlin, Germany, 254 pp., approx. $5.00, 1957—This is a revised edition on the smelting of aluminum scrap with emphasis on the new types of furnaces used.

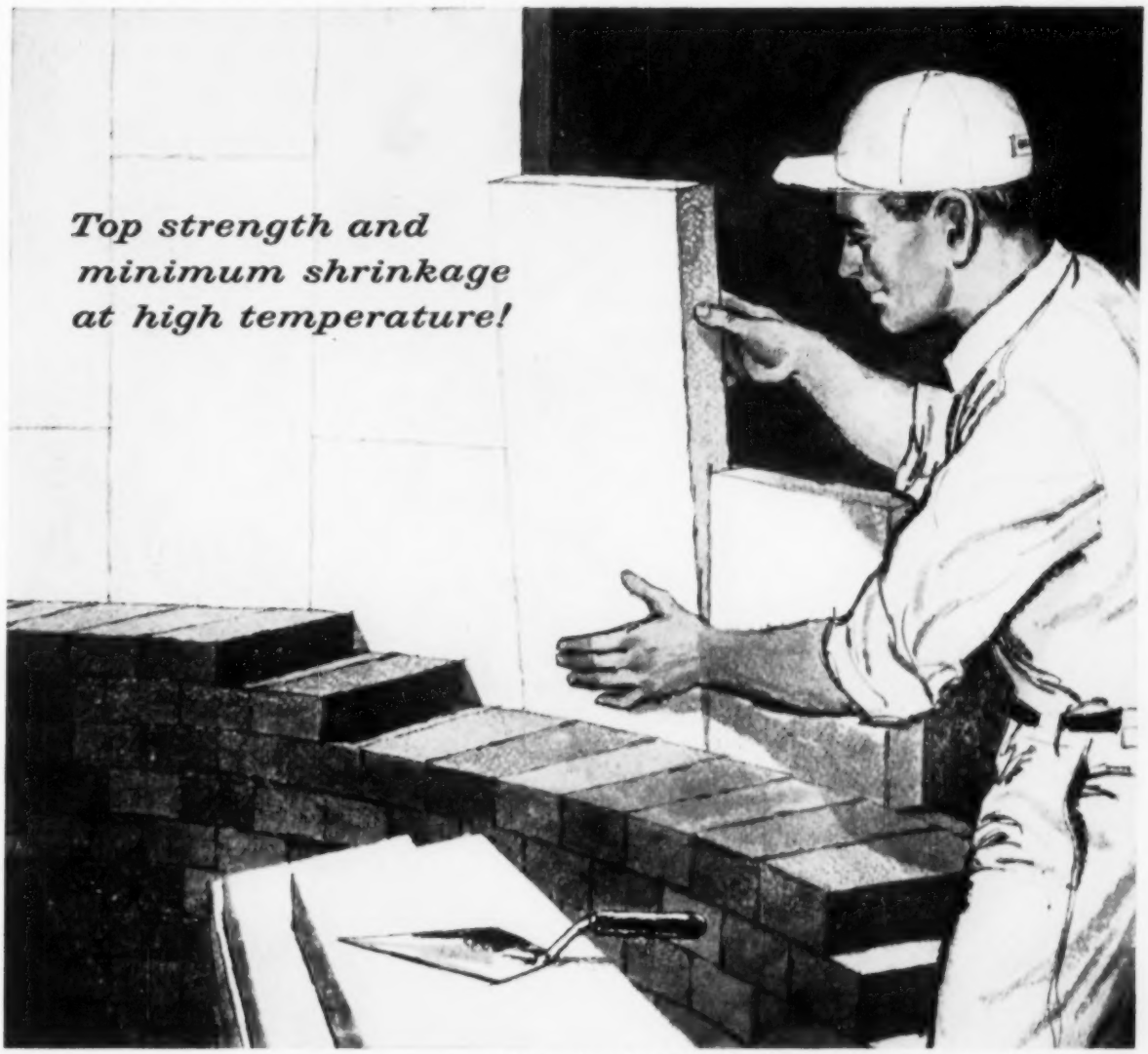
Solid State Physics, Adrianus J. Dekker, *Prentice-Hall Inc.*, 540 pp., $9.00, 1957—Both topics that can be discussed without reference to the electron theory of solids and those that deal with the electronic properties of solids are covered. Five appendices give essential data on thermodynamics, wave mechanics, and quantum statistics. The book is suitable for use as a text or for self-study by engineers new to the field. •

Semiconductor Abstracts Vol. 3, compiled by Battelle Memorial Institute, *John Wiley & Sons. Inc.*, 322 pp., $10.00, 1957—Continuing this series, the volume contains over 1250 abstracts on the properties and applications of semiconducting and luminescent materials. References are grouped under materials and there is a separate section on general theories. •

Physics of Non-Destructive Testing, supplement No. 6, British Journal of Applied Physics, *Institute of Physics*, London S.K.W.1, England, 72 pp., approx. $3.50, 1957.—A collection of 11 papers and 2 panel discussions published to give engineers and metallurgists an insight into newer methods of nondestructive testing and their uses. Two brief symposiums are also included, one on optical and surface methods, the other on penetrant methods.

The Physics of Flow Through Porous Media, Adrian E. Scheidegger, *The Macmillan Co.*, 60 Fifth Avenue, New York 11, N. Y., 236 pp., $14.00, 1957—This volume correlates

(Continued on page 1333)



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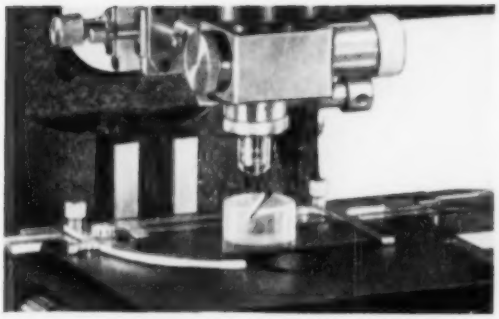

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Books

(*Continued from page 1328*)

the essence of information on hydro dynamics in porous media. It covers the physical theories of flow and covers methods for the solution of various flow problems. •

The Manufacture of Iron and Steel, Vol. 1, Iron Production, Reginald Bashforth, *Chapman & Hall Ltd.*, London W.C.2, England, 306 pp., approx. $7.00, 1957.—This is a comprehensive survey on modern methods of iron manufacture of ferroalloys, special irons, and wrought irons. The blast furnace is also thoroughly covered as are the various methods of pig iron production.

The Foundations of Metallography, Georg Masing, Monograph and Report Series No. 21, *The Institute of Metals*, London S.W.1, England, 166 pp., $3.50, 1957.—This book is a concise introduction for students of metallurgy, covering a variety of subjects including the atomic structure of metals and alloys and the structure of alloys in systems with and without solid solutions or compounds. The book is a translation from the fourth German edition published in 1955.

Gmelin: Handbuch der Anorganischen Chemie, System No. 28, Calcium, Part A, Section 2, available from *D. R. Stein*, 1074 Washington Ave., Pelham Manor, N. Y., 488 pp., $55.68, 1957.—The major part of this volume is devoted to the geochemistry of calcium, the industrially important deposits of fluorspar, calcium phosphate, and gypsum, with a descriptive summary of calcium minerals. •

Gmelin: Handbuch der Anorganischen Chemie, System No. 32, Zinc, Supplementary Volume, available from *D. R. Stein*, 1074 Washington Ave., Pelham Manor, N. Y., 1025 pp., $138.00, 1956.—This volume deals with the geochemistry of zinc and its economic geography; technical preparation, including ore dressing, electrolytic production, and refining; physical properties, electrochemical behavior of zinc; and a considerable section on the major alloys of zinc. •

The Isotope Index, *Scientific Equipment Co.*, Publications Dept., 23 N. Hawthorne Lane, Indianapolis 19, Ind., $3.00, 1957.—This second edition of the Index lists the source of all commercially available isotopes, including both stable and radioactive isotopes and many isotope-labeled compounds. Also included is complete purchasing information.

Phase Diagrams in Metallurgy, Frederick N. Rhines, *McGraw-Hill Book Co. Inc.*, 340 pp., $12.00, 1957.—This text is for the undergraduate

(*Continued on page 1342*)

ERASE HYDROGEN, OXYGEN AND NITROGEN FROM YOUR MELT!

The elimination of contaminating gases imparts much more than improved grain structure to ferrous and non-ferrous metals. Metallurgists find that High Vacuum imparts distinctly new attributes and that, in *many* cases, the end product might well be considered an entirely new one.

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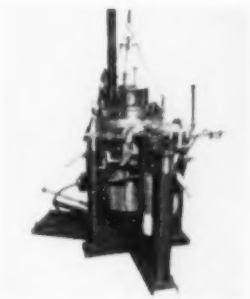

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Over 60 ductile cast iron runout table rolls are already in service on the new 54-inch, continuous, hot-strip mill at Weirton Steel Company, division of National Steel Corporation.

Weirton plans to replace *all* the mill's original cast iron rolls as they wear out, with the new ductile iron type.

Weirton is changing because tests showed ductile iron rolls outlast any rolls used before. They resist warpage and cracking under thermal shock. They are tougher and, consequently, stand up under continuous shock and vibration. And, ductile iron rolls have good wear resistance.

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Russian Steel Industry's Plans Revealed

"The European Steel Market in 1956", prepared by the Economic Commission for Europe and recently issued by the United Nations, reveals information on eastern Europe heretofore unavailable.

Satellite dependence on Russian raw materials

Iron and steel plants of the eastern European countries built since World War II are largely based on supplies of Russian raw materials. Thus, 1956 iron ore exports of the USSR were more than 9 million metric tons, some 3 million each being supplied to Poland and Czechoslovakia, with Hungary and Eastern Germany receiving more than 1 million tons each. Coke exports from the USSR, amounting to 1.7 million metric tons, went to Eastern Germany, Hungary, and Rumania. Poland drastically reduced coal and coke exports but still exported 2.3 million metric tons of coke in 1956.

Open hearth predominates

Of the Russian 1956 steel output of 48.6 million metric tons, some 42.9 million was open hearth, 3.7 million electric furnace, and only 2.0 million bessemer. A similar pattern holds true of the other eastern European countries. On the blast furnace side, average USSR charge was 60 pct sinter with a coke rate of 862 kg per metric ton of iron. Elsewhere less sinter was charged, and coke rates were higher.

1960—Expanded production but inadequate ore supplies

By 1960 the countries of eastern Europe will have a combined crude steel capacity of 87.4 million metric tons, with 68.3 for the USSR. Russia plans an output of 114 million metric tons of iron ore, 73 million tons of sinter, 64.5 million tons of coke, and 53 million tons of pig iron. Proportional increases are planned in the other countries, but the present trade pattern in raw materials will be maintained. For the region as a whole, the UN report concludes, "It seems, therefore, that from an over-all point of view there will be little or no deficit of coke in 1960", but, "So far as iron ore is concerned the situation is more difficult, since only the USSR and Bulgaria are likely to be in a position to export . . . it seems likely that there will be a significant iron ore deficit in eastern Europe in 1960".

Toward oxygen steel and continuous casting

By 1960, 40 pct of the steel production in the USSR will utilize oxygen, including all converter steel; duplexing is to be increased, mainly converter plus electric furnace; and open-hearth furnaces are to be lined with chrome-magnesite refractories. At least one plant-scale continuous casting line will be in operation. In the other countries, following the Russian example, the major effort is toward increased sinter charge, constant humidity, high top pressure, and automatic regulation.

Four new wide-strip mills

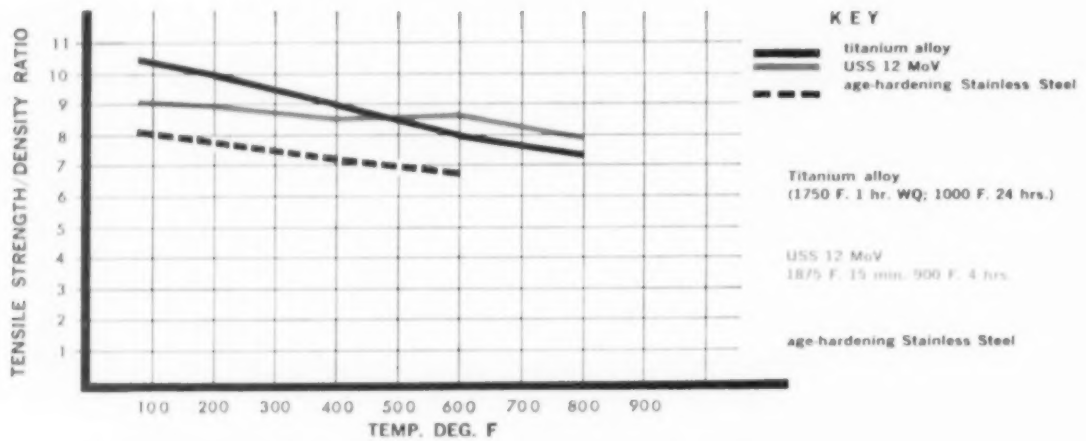
The current plan in the USSR includes a second continuous 80-in. hot strip mill at Magnitogorsk, a continuous 80-in. mill at Karaganda; a semi-continuous 67-in. mill at Voroshilov; and a 67-in. semi-continuous mill at Tcherepovets. With these mills in operation total output of coils in the USSR will be over 12 million tons. The second Magnitgorsk mill is now under construction, but it is understood that the other three have not yet been started. In Poland, the continuous strip mill at Nowa Huta is expected to be in full production by 1960.

New USS 12 MoV martensitic to an ultimate tensile strength

Typical Performance Data:

TEST TEMPERATURE, F.	YIELD STRENGTH (0.2% OFFSET), PSI	TENSILE STRENGTH, PSI	ELONGATION IN 2 INCHES, PER CENT
	TEMPER 800 F. ← 4 hours air-cool		
room	204,200	244,000	10.0
200	192,500	239,500	11.2
300	183,000	237,750	10.6
400	180,500	236,000	10.5
500	180,000	243,900	10.6
600	173,750	244,500	9.7
700	172,750	239,500	11.5
800	164,000	228,800	10.3
900	158,700	223,500	7.5
	TEMPER 900 F. ← 4 hours air-cool		
room	194,700	247,000	10.5
200	187,250	242,000	12.3
300	184,000	235,000	11.8
400	178,500	231,000	10.3
500	174,500	230,500	10.2
600	173,750	232,000	9.5
700	172,750	229,500	9.9
800	164,250	224,500	9.5
900	164,250	210,250	7.3
1000	142,500	177,500	5.8

Average elevated temperatures tensile properties of 0.10-thick USS 12 MoV previously heat-treated for 15 minutes at 1850° F. and tempered as indicated.



Tensile strength/density ratios for three metals at various temperatures—a comparison between USS 12 MoV, a currently available titanium alloy, and an age-hardening Stainless Steel. Notice superiority of USS 12 MoV at temperatures above 550° F.

U N I T E D S T A T E S S T E E L

steel can be heat-treated of 240,000 psi . . .

230,000 psi guaranteed at room temperature!

In the development of special steels for aircraft use, United States Steel has concentrated on martensitic structures—because they are capable of attaining the highest tensile strength for a given amount of ductility.

USS 12 MoV (Type 422 modified) is one of the most promising steels to result from this program. It can be heat-treated to develop a nominal ultimate tensile strength of 240,000 psi. *Guaranteed minimum tensile strength at room temperature is 230,000 psi.*

Recommended Heat Treatment:

1. Heat for 15 minutes at 1850° F. Air-cool.
2. Temper four hours at a specific temperature within the range of 600°-900° F.
3. Air-cool.

Physical Constants:

Density	.279 lbs./cu. in.
Coef. of Thermal Expansion	7.03 x 10-6/F.*
M_s Temperature	590° F.

*Average expansion over the range R.T. to 1500° F.

Chemical Composition:

C	Cr.	Mo	V
0.20/0.30	12.0	1.0	0.25

Mechanical Properties—Annealed

USS 12 MoV can be furnished with the following typical annealed properties:

Tensile Strength, psi	100,000
Yield Strength, psi	65,000
Elongation, % in 2"	25
Rockwell B	90

After fabrication, following the recommended method of heat treatment, USS 12 MoV can be heat-treated to a minimum guaranteed tensile strength of 230,000 psi at room temperature.

Corrosion Properties:

Like other 12% chromium steels, USS 12 MoV is resistant to atmospheric corrosion in the sense that it does not lose weight. In time it will discolor, or, in certain environments it may develop a light rust film. This will not harm mechanical properties.

Availability:

USS 12 MoV sheets can be produced in the annealed condition in widths up to 48", thicknesses from .015" to under 3/16", stretcher-leveled lengths up to (180") (192") or (196") depending on gage. It may also be produced in a range of plate, bar, strip and wire sizes. Further information on request.

USS 12 MoV is typical of United States Steel research and development efforts to produce aircraft steels of high strength which will maintain this high strength at elevated temperatures along with good corrosion resistance properties. Other special steels for aircraft being developed or manufactured by United States Steel include USS Tenelon Stainless Steel, USS Strux, USS "T-1" Steel, 4130 and 4330.

Watch for further data on these steels in future United States Steel advertisements.

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This new exothermic manganese alloy allows open hearth melters to make higher additions of manganese to the ladle (up to 1.5% manganese). Thus you get:

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The strong exothermic action of MANTEMP ferromanganese sharply reduces segregation of manganese within the ladle. In addition, its unique exothermic reaction allows higher and more consistent recoveries of aluminum when aluminum is added as an alloying element.

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Shown at Bell Laboratories, Murray Hill, N. J., are, left to right, F. J. Herr, S. T. Brewer, L. R. Snoke, E. E. Zajac and F. W. Kinsman.

They're wiring the seas for sound

These five Bell Labs scientists and engineers may never "go down to the sea in ships." Yet, they're part of one of the most exciting sea adventures of modern times. Along with many other specialists, they are developing the deep-sea telephone cable systems of the future.

Here's how they join many phases of communications science and engineering—to bring people who are oceans apart within speaking distance.

F. J. Herr, M.S., Stevens Institute, is concerned with systems design and analysis. He studies the feasibility of new approaches and carries out analysis programs to select optimum parameters for a proposed system design.

S. T. Brewer, M.S. in E.E., Purdue, communications and electronics engineer, explores new designs for sea-bottom amplifiers needed to step up power of hundreds of simultaneous telephone conversations.

L. R. Snoke, B.S. in Forestry, Penn State, is the team biologist. He investigates the resistance of materials to chemical and microbiological attack in sea water. Materials are evaluated both in the laboratory and in the ocean.

E. E. Zajac, Ph.D. in Engineering Mechanics, Stanford, is a mathematician. He studies the kinematics of cable laying and recovery. Cable's dynamic characteristics, ship's motion, the mountains and valleys in the ocean bottom—all must be taken into account.

F. W. Kinsman, Ph.D. in Engineering, Cornell, solves the shipboard problems of storage, handling and "overboarding" of cable. New machinery for laying cable is being developed.

Deep-sea cables once were limited to transmitting telegraph signals. Bell Labs research gave the long undersea cable a voice. New research and development at the Labs will make this voice even more useful.

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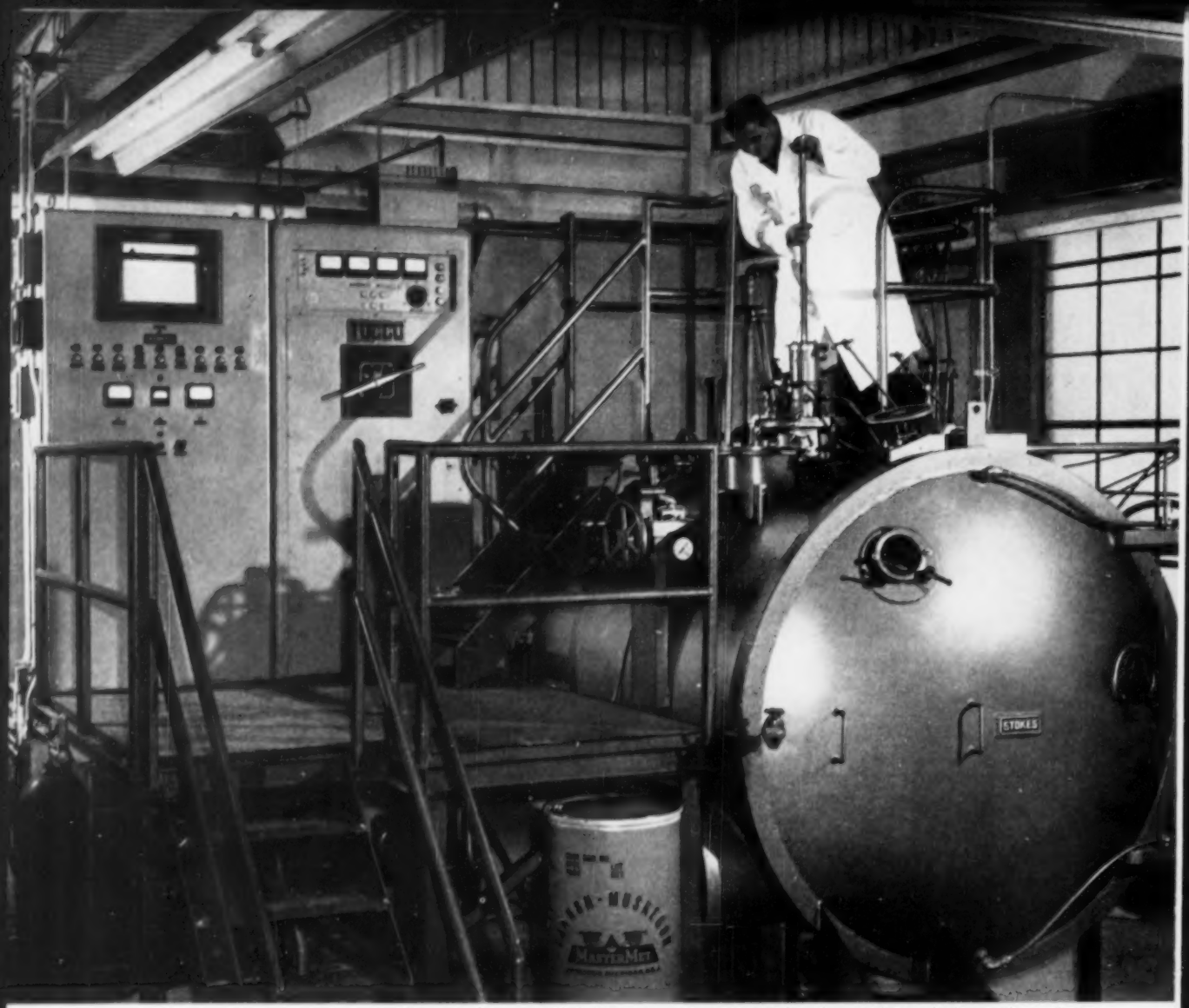
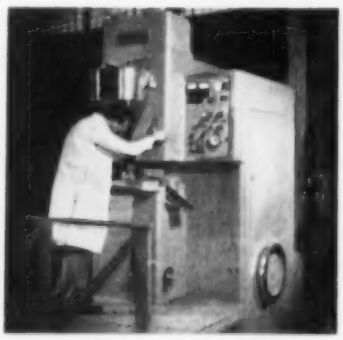


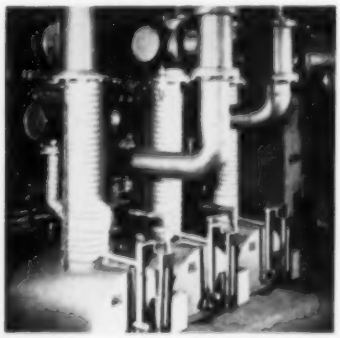
Due to Stoke. vacuum lock design, operators can manipulate the melt during the heat without releasing vacuum. Furnace is used for production of special alloys at Cannon-Muskegon Corporation, Muskegon, Mich.

The metals industry is profiting from the use of other STOKES production equipment

Vacuum Metallizers. Stokes offers a complete line of vacuum metallizing equipment to plate metals for improved surface finish . . . also to provide conductive coatings on non-conductive materials.



Powder Metal Presses. Cost savings and the compacting of incompatible alloys have made powder metallurgy an accepted process. Stokes offers the most complete line of presses in the industry.



Vacuum Pumps. For rapid evacuation and holding high vacuums, Stokes offers mechanical pumps, and "Ring-Jet" oil vapor diffusion and booster pumps. New design affords 10 to 100% greater speeds.

"MasterMet" high temperature alloys vacuum melted in Stokes furnace

Another example of how Stokes vacuum furnaces aid industrial utilization of the new technology of vacuum metallurgy.

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Reference Data:

Microvac Pumps—Catalog 750
Diffusion and Booster Pumps
Specification and performance data
Story of the Ring-Jet Pump
How to Care for Your Vacuum Pump—
Booklet 755
Vacuum Furnaces—Catalog 790
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From the Desk of the President

To: Purchasing Department

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Books

(Continued from page 1333)

student and is organized to display the subject, thus presenting material on the binary, ternary, and quaternary levels. •

National Science Foundation publications are now available and lists will be sent upon request. Address inquiries to Publications Office, National Science Foundation, Washington 25, D. C.

Stress Corrosion Cracking and Embrittlement, ed. by William D. Robertson, *John Wiley & Sons Inc.*, 202 pp., $7.50, 1956.—Under the auspices of the Corrosion Div., Electrochemical Soc., this book treats the major developments during the last 12 years in the field of stress corrosion cracking and embrittlement. •

Nuclear Engineering, ed. by Charles F. Bonilla, *McGraw-Hill Book Co. Inc.*, 850 pp., $12.50, 1957.—This reference work gives the basic principles of the main engineering disciplines involved in the designs of nuclear reactor cores and power plants. It also provides the necessary background in nuclear physics and reactor physics. •

ASTM Proceedings, *American Society for Testing Materials,* 1916 Race St., Philadelphia 3, Pa., 1510 pp., $12.00, 1957.—The 1956 edition contains reports of 80 technical committees with appendices and 52 technical papers with discussions. Many of these reports were given at the Society's national meetings. •

Solvent Extraction in Analytical Chemistry, George H. Morrison and Henry Freiser, *John Wiley & Sons Inc.*, 269 pp., $6.75, 1957.—This book, the first of its kind, offers comprehensive coverage of trace concentrations, the first section being devoted to principles and the second to the practical aspects, including apparatus and techniques. •

Proceedings of the 1957 National Industrial Research Conference, *Armour Research Foundation* of Illinois Institute of Technology, 35 W. 33 St., Chicago 16, Ill., $6.00, 1957.—The proceedings include 12 papers on management level decisions on research and development which were presented by top executives at the conference in Chicago in April. The papers deal with sales growth through research.

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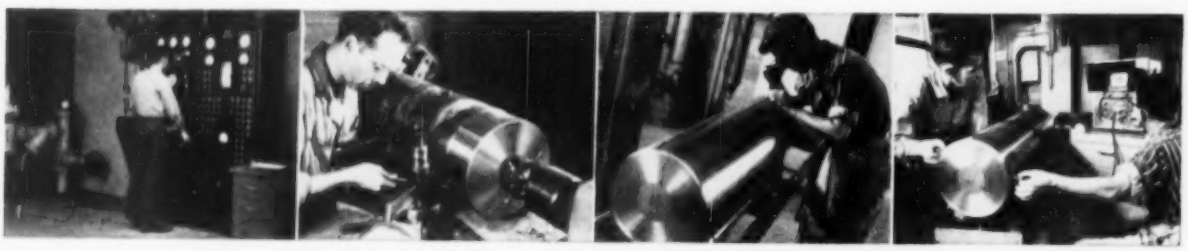

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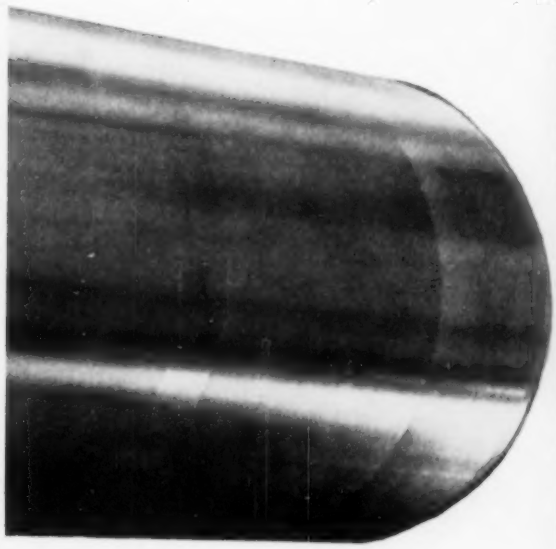

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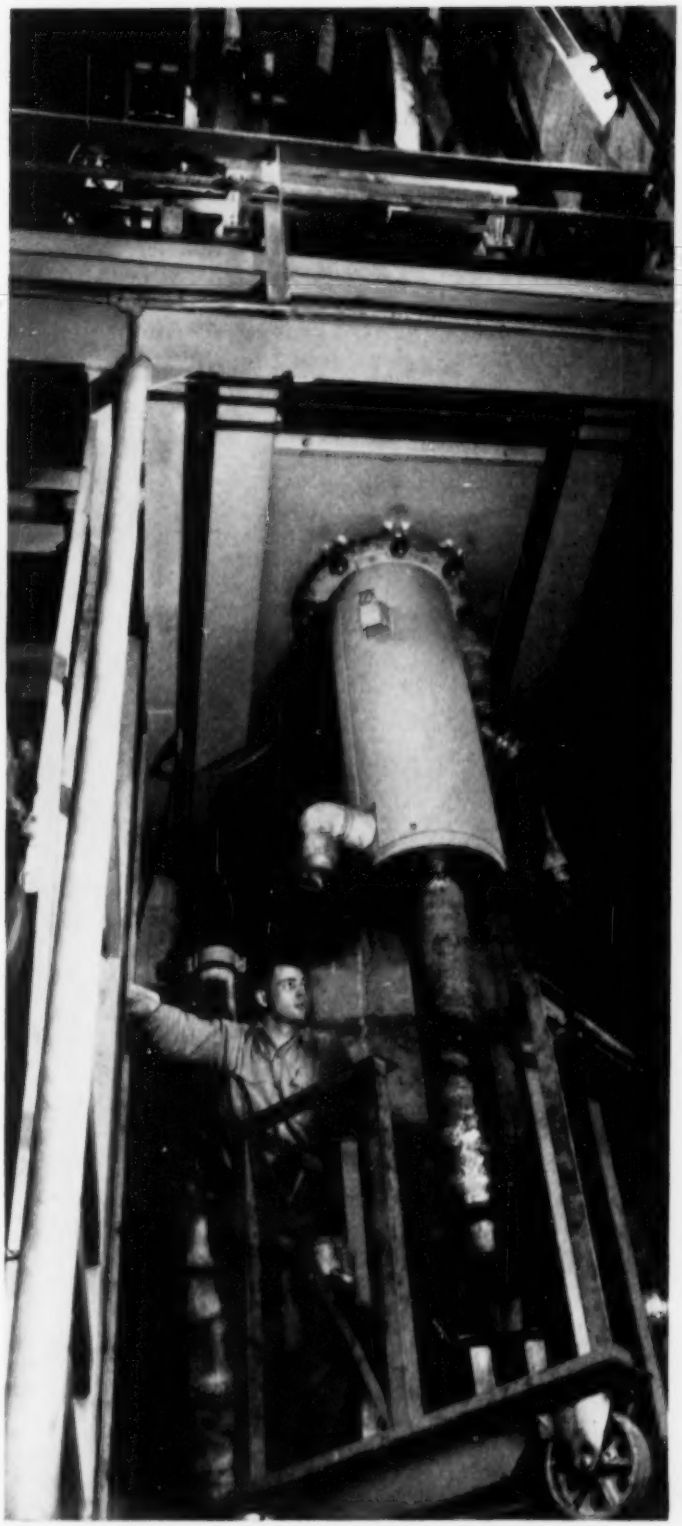

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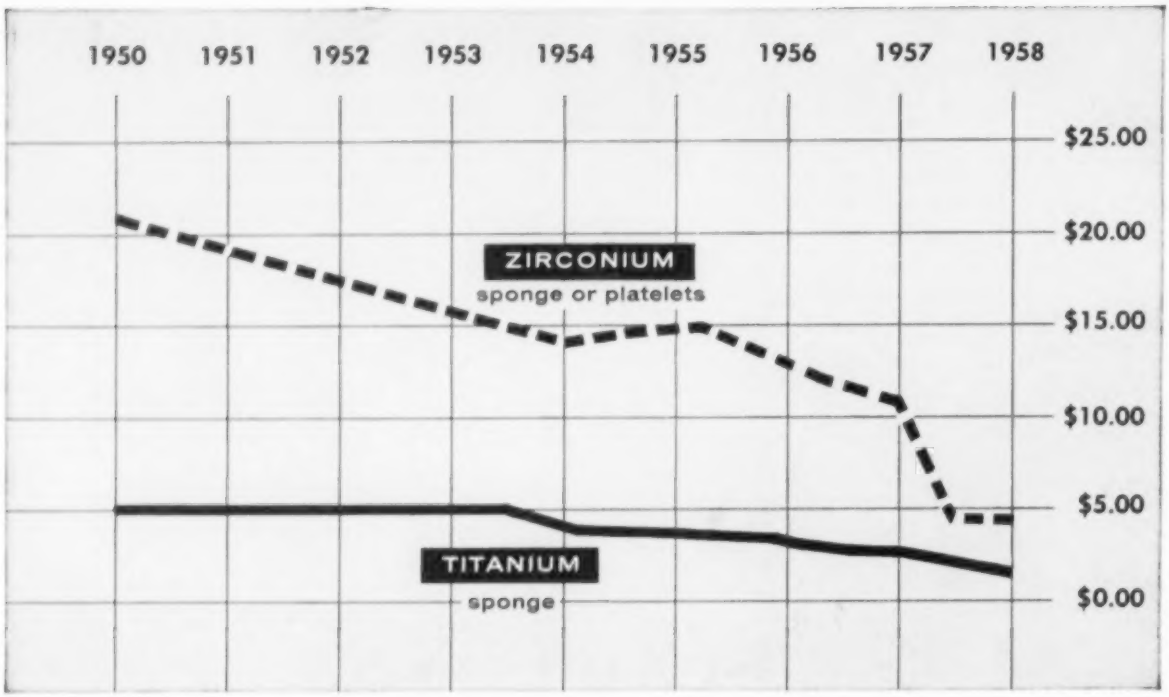
Production Pioneer of ZIRCONIUM



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Now is the time to do some new thinking about titanium and zirconium. These metals with their many advantages will soon be *much more plentiful* at *much lower cost*. Reason: U.S.I. will be coming onstream shortly with a 10-million pound per year titanium plant AND a zirconium plant which will supply one million pounds of that metal to industry.

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Write to Bill Greenleaf, U.S.I. Manager of Metals Department, for more information on these new metals from U.S.I.

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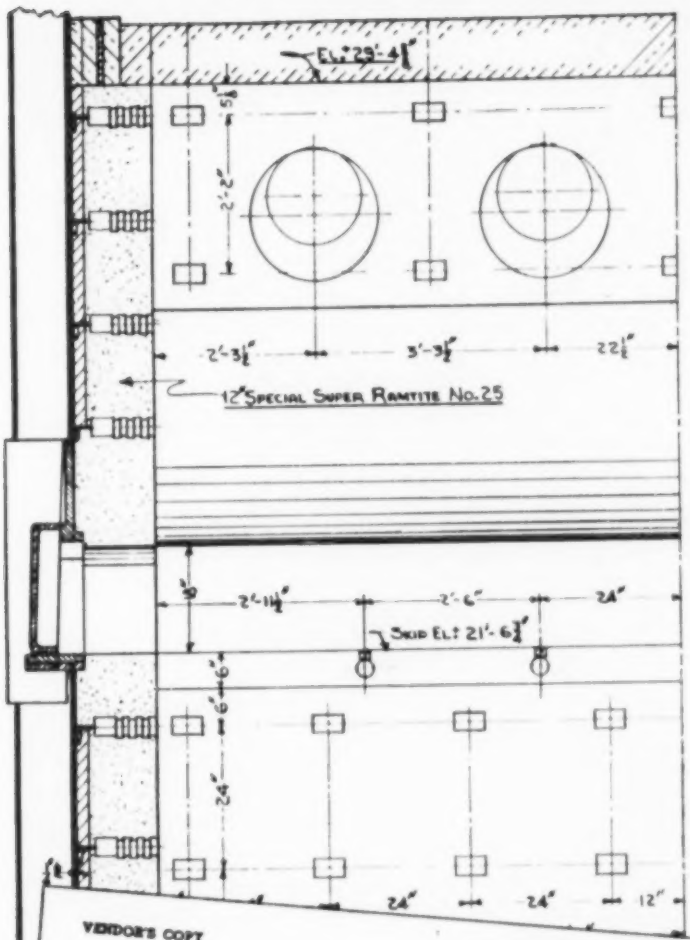

In 1954, Ramtite was installed in the side and burner walls of two billet heating furnaces at a midwestern steel mill. These furnaces were recently completely redesigned by Flinn & Dreffein Engineering Co., and once again Ramtite was ordered for the side walls and burner walls. Here's why!

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The Ramtite Co. offers you a complete sales engineering service—experienced men who are always available to study your refractory problems and consult with your Engineering, Mason and Ceramic Departments about your specific needs.

For further information, contact your local Ramtite representative.

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This is another in a series of advertisements depicting ways Ramtite Refractories serve the steel industry.

See it at the Show*

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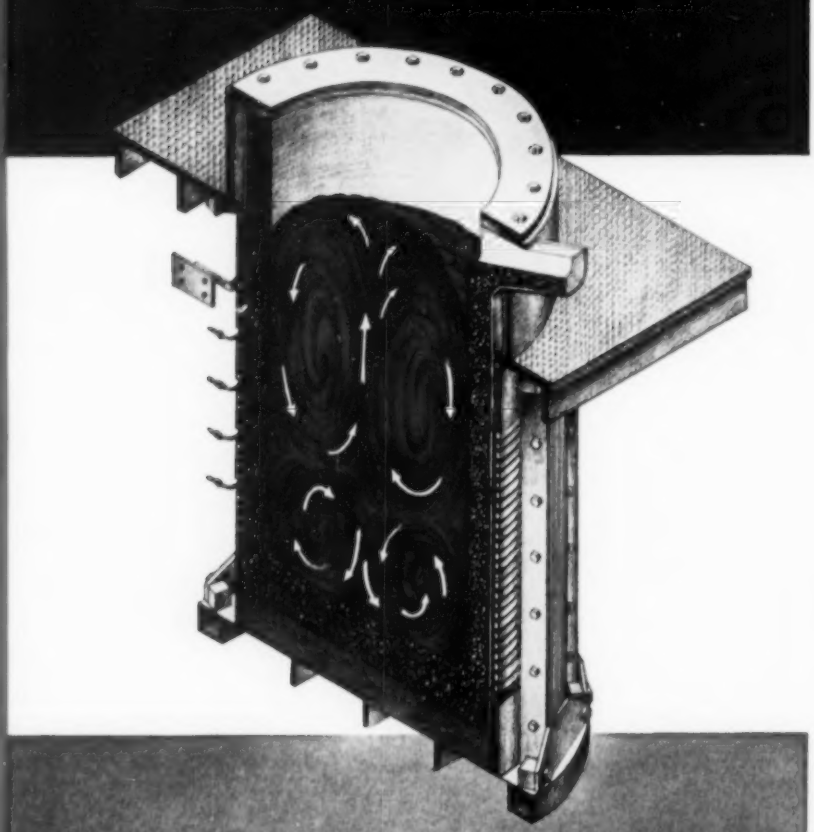

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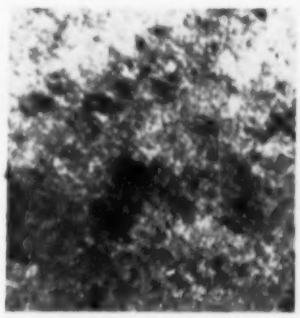

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Columbium and Niobium:

Who Threw the Monkeywrench

by J. J. Burke

On November 26 of the year 1801, Charles Hatchett read a paper before the Royal Society in London entitled, *An Analysis of a Mineral Substance From North America, Containing a Metal Hitherto Unknown.*[1] The mineral was originally sent to Sir Hans Sloane of the British Museum by Mr. Winthrop of Massachusetts. The paper concludes with the following sentence:

> "Considering, therefore, that the metal which has been examined is so very different from those hitherto discovered, it appeared proper that it should be distinguished by a peculiar name; and, having consulted with several of the eminent and ingenious chemists of this country, I have been induced to give it the name of Columbium."

The ore from which this new metal was extracted was given the universally accepted name of columbite. The element itself has suffered a harder fate, and it comes down to us with two names: columbium and niobium, and a history of accident, paradox, and controversy which has raged unabated for over 150 years.

History marked by confusion

The reasons for this duality are somewhat involved, and in some places the evidence is contradictory, but the basic facts appear to be as follows:

In 1802, a year after Hatchett's discovery of columbium, Ekeberg, in Sweden, discovered another element which he called tantalum, in Finnish minerals now known as tantalite and yttrotantalite. A short time later, Wollaston erroneously reported that the two metals were identical, and the name columbium came into general use in this country, while tantalum was used in Europe. Many scientists used the two interchangeably. Wollaston also reported that the same metal was found in a mineral from Bodenmais in Bavaria. The ore was known alternately as the columbite of Bodenmais and Bavarian tantalite.

Over the next 40 years, the mistaken idea became well established that columbium and tantalum were one and the same. Firmly believing this, H. Rose published the first of three articles in the *Chemical Gazette*.[2] He determined that Ekeberg's Finland tantalites contained a single metal, tantalum (also called columbium), thus confirming Ekeberg's work. He differed with Wollaston, by saynig that the Bavarian minerals contained at least one *new* metal, niobium, and most likely two, the other being named pelopium. Pelopium was very closely allied with tantalum (columbium), and it wasn't until the second article,[3] published a year later, that he was sure that pelopium and tantalum were distinct. The third article,[4] published eight years later, confirmed the fact that pelopium and tantalum were distinct, but admitted that pelopium and the previously identified niobium were one and the same. Prof. Rose decided that the proper name for the new metal should be niobium:

> "As however, in any case, pelopic and niobic acids are oxides of the same metal, the later must receive only a single name. The author decides in favor of the name niobium."

This was the last time anything was ever written about pelopium.

Thus, the situation in 1854 is as follows: Hatchett's columbium and Ekeberg's tantalum are erroneously thought to be one and the same, and are called columbium in this country and tantalum in Europe. A supposed new metal has been found in Bavarian and American ores that Rose has named niobium.

If Rose had chosen to recognize Hatchett's prior discovery and call it columbium instead of niobium, the value of his work would have been to clear up the confusion arising from Wollaston's report and confirm both Hatchett's and Ekeberg's work. Instead of clearing the confusion, he compounded it. By the time it was realized that Hatchett's columbium was not Ekeberg's tantalum but rather Rose's niobium, usage had given niobium something of an advantage; *reducto ad absurdum*.

Attempts to clear the air

The first article criticizing this state of affairs appeared in the *Philosophical Magazine and Journal of Science* in June 1854.[5] The author, a Prof. A. Connell, recognizes Rose's mistake, and speaking of niobium says:

EDITORIAL

into the Periodic Table?

> "Does it not follow very clearly that this metal ought to have the name of columbium? M. Rose has now come to the same conclusion at which Mr. Hatchett arrived fifty years ago, when he announced that one new metal, to which he gave the name of columbium, existed in the American mineral columbite."

But Prof. Connell's main point is to clear up the still-existing confusion of columbium with tantalum. He closes his article with the following:

> "Of all courses, one of the most ill-advised seems that followed by some English chemists, of giving occasionally the name of columbium to tantalum, which as I understand the matter, is now quite ascertained to be different from any of the other metals. This course can only lead to confusion. Tantalum is not columbium."

By 1877, tantalum was known to be distinct, but columbium and niobium had grown into synonomous use. Articles by J. Lawrence Smith of Louisville, appearing both here and abroad,[7] called for restoration of the original name:

> ". . .it is but right, just, and in accordance with chemical and mineralogical precedence, that the name given by the discoverer should replace that of niobium, which originated forty-five years later."

And so the problem has come down through the years. To all commercial users of the metal, columbium is the accepted name; columbium-stabilized stainless steel (type 347) is a standard grade. Yet, the chemists and many metallurgists still insist on niobium. In 1949, this insistence took the form of a resolution of the International Union of Pure and Applied Chemistry, quickly concurred in by the American Chemical Society and the National Research Council, adapting niobium as the proper name (a similar resolution adapting the name wolfram for tungsten was later rescinded). Objections to the adoption of niobium were made in trade journals representing commercial users of the metal:

> ". . .we urge the IUPAC and the chemical profession to reconsider the case of element 41 in favor of columbium, the name long accepted by the only industry that uses the metal commercially."[8]

At the present time, with the metal playing an increasingly important role in high-temperature metals and reactor technology, the need for a single name becomes more and more necessary. At the recent EJC Nuclear Congress, papers dealing with it were about evenly divided. The U. S. Bureau of Mines uses both names. Men working in the field are increasingly aware of the need for a single name:

> "Niobium will very likely become a much more important element in future metallurgical technology than it has been in the past. Particularly as far as its use as a metal or alloy rather than an alloying addition to other metals. It will become increasingly confusing to use two different names for the element. A uniform name relative among metallurgists is important."[9]

It is certainly within the scope of the AIME to take a firm stand on this subject. Niobium is not the proper name for element 41; and a wrong, even though far removed in time and space from its inception, remains a wrong. On the other hand, niobium carries the endorsement of leading chemical societies. The question is open—members with feelings either way should make those feelings known in the councils of the Institute. A positive stand will go a long way in helping to clear the air on this perplexing subject.

Until that time, the editors of AIME journals will, in order to minimize the confusion, use the name columbium exclusively.

References

[1] C. Hatchett: An Analysis of a Mineral Substance from North America, Containing a Metal Hitherto Unknown, *Philosophical Transactions*, London, 1802.

[2] H. Rose: *Chemical Gazette*, 1845, W. Francis, ed., vol. 3, p. 35, London, Taylor & Francis, pubs.

[3] *ibid.*, 1846, vol. 4, p. 349.

[4] *ibid.*, 1854, vol. 12, p. 150.

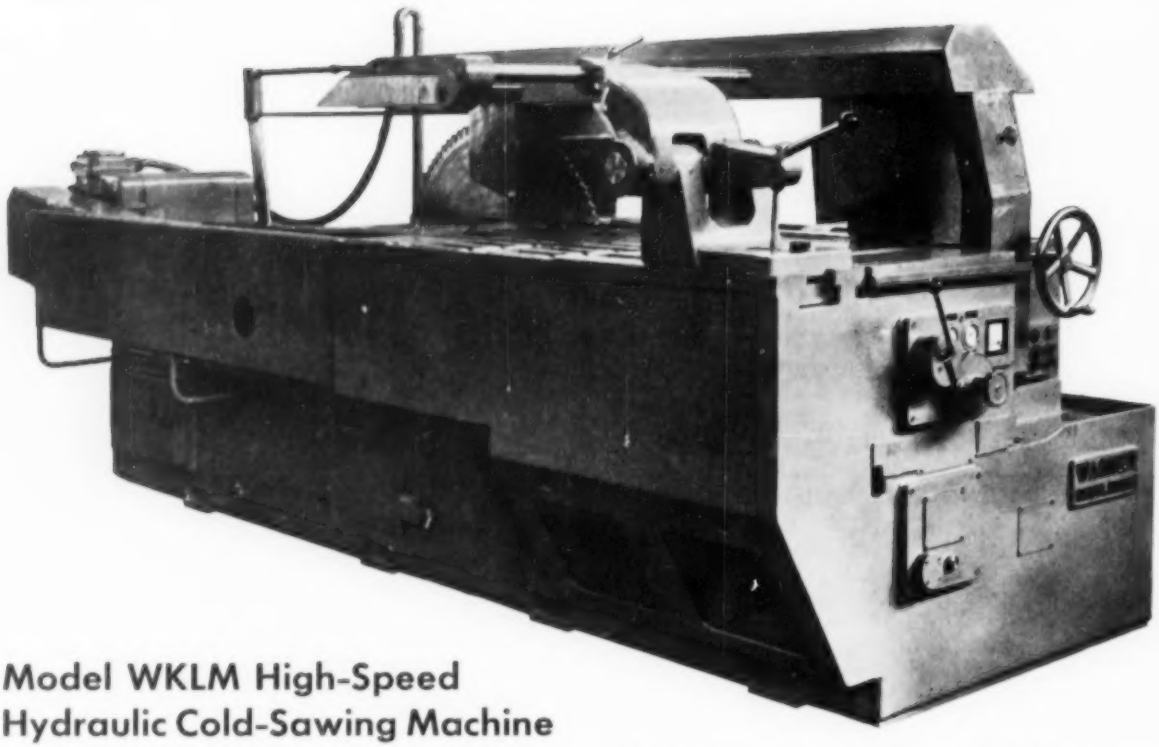
[5] A. Connell: *Philosophical Magazine and Journal of Science*, 1854, Series 4, vol. 7, No. 46, p. 461.

[6] J. L. Smith: *American Journal of Science*, 1877, Dana, Silliman, & Dana, eds., 3d Series, vol. 13, No. 77, p. 359; *Annales de Chimie et de Physique*, Paris, 1877, vol. 12, p. 253.

[7] *Materials & Methods*, 1956, vol. 44, No. 11, p. 103.

[8] J. H. Bechtold: Mgr., Metallurgy Dept., Westinghouse Research Laboratories, private communication.

AGAIN LEADS THE FIELD



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FALL MEETING REPORT

Institute of Metals Division, Iron and Steel Division (Page 61), November 3-7, 1957, Morrison Hotel, Chicago, Illinois.

GENERAL INFORMATION

Registration: To minimize confusion on Monday morning, registration facilities will be available on the First Floor Foyer of the Morrison Hotel on Sunday, November 3, from 3:00 until 9:00 pm. If you are in Chicago on Sunday, please register in advance. The registration fee is $2 to AIME members, $4 to nonmembers, and $1 to students. The fee includes a set of reprinted papers or abstracts as long as the supply lasts. There will be no registration fee for Student Associates of AIME nor for those attending the dinner only. Students are requested to register. In addition to the above mentioned advance registration facilities, you may register on the First Floor Foyer of the Morrison Hotel on Monday, Tuesday, and Wednesday from 8:00 am to 4:00 pm, and on Thursday from 9:00 am to 3:00 pm.

Features: In recognition of the Second World Metallurgical Congress, being held simultaneously with the 39th National Metal Congress and Exposition, a number of the sessions under sponsorship of AIME have been designed to interest visitors from abroad as well as AIME members and guests from the United States. The IMD High-Temperature Alloys Committee has arranged a Symposium on the "Relation of Structure and High-Temperature Properties" to be held on Monday morning and afternoon, and Wednesday afternoon.

The IMD Committee on the Chemistry and Physics of Metals has arranged two days of special sessions. On Monday, the topic is "Structure of Solid Solutions" with a Seminar in the morning, and the presentation of Research Summaries in the afternoon. On Tuesday morning a Seminar on "Science of Metal Hardening" is scheduled. Research Summaries on the same subject will be presented on Tuesday afternoon.

The Sixth Annual Titanium Symposium will be held on Tuesday morning and afternoon. At the morning session, the topic will be "Titanium's Progress at Home and Abroad." In the afternoon, a panel discussion will be conducted on "The Manufacture and Use of Titanium."

A Symposium on Uranium and Uranium Dioxide will be held on Wednesday morning and afternoon. Papers will be presented on the melting, casting, forging, rolling, cold working, and welding of uranium, and on the preparation and fabrication of uranium dioxide.

This year, a fourth day of technical sessions will be held on Thursday. One of the features is the Symposium on Powder Metallurgy, to be followed by a special luncheon.

In accordance with the changed procedure for presentation of papers, as described in the May JOURNAL OF METALS, five sessions have been scheduled based on the submission of research abstracts; a total of 48 papers will be presented. In addition 14 additional papers based on submission of abstracts are scheduled for the Monday and Tuesday afternoon sessions arranged by the Committee on Chemistry and Physics of Metals.

VOLUME IV ON "NUCLEAR METALLURGY"

The majority of the papers to be presented at the Symposium arranged by the IMD Nuclear Metallurgy Committee on "Uranium and Uranium Dioxide" have been printed in a book entitled "Nuclear Metallurgy" (Vol. IV).

Purchase your copy at the Registration Desk, or order by mail from AIME Headquarters, 29 West 39th Street, New York 18, N. Y.

Price: $7.00 (For AIME Members, $5.00)

Special Price: $5.00 to all Registrants at Fall Meeting

(Copies of "Nuclear Metallurgy," Vols. I, II, and III also available)

GENERAL INFORMATION

Special Iron and Steel Sessions: The Iron and Steel Division has arranged special technical sessions to be presented at the Morrison Hotel during the IMD Fall Meeting. It is intended that they be of more than ordinary interest to the visitors from abroad. On Tuesday morning the topic is "Recent Developments in Steelmaking Practices," with papers on vacuum arc melting, continuous casting, and nitrogen content of steel. Tuesday afternoon, a panel discussion will be held on continuous steelmaking. Details of the Iron and Steel Sessions will be found on pages 00 and 00.

Authors' and Chairmen's Breakfasts: The breakfast for Monday session chairmen and authors who will present papers at Monday sessions is scheduled at 8:00 am in Parlor B, Monday, November 4. For chairmen and authors on Tuesday sessions, the breakfast will be held in Parlor B at 7:30 am on Tuesday, November 5. The breakfast in Parlor B at 7:30 am on Wednesday, November 6, will be for both Wednesday and Thursday authors and chairmen.

Annual Fall Dinner: The annual fall dinner will be held in the Cotillion Room of the Morrison Hotel on Tuesday, November 5, at 7:00 pm. At 6:30 pm there will be a cocktail party in the Embassy Room for dinner guests. Tickets for the dinner will admit the holder to the cocktail party. Ladies are cordially invited to the cocktail party and dinner. Dress will be informal (business suits).

Dinner tickets will cost $7 each and will be on sale at the registration desk in the Morrison Hotel during the meeting. Registrants are urged to buy their tickets early when they register to enable the Local Committee to plan the best party possible. The speaker of the evening is to be Professor John

Coming Events

1957	
Nov. 18-21	AIME Conference on Magnetism and Magnetic Materials, Sheraton-Park Hotel, Washington, D. C.
Dec. 4-6	AIME 15th Electric Furnace Steel Conference, Penn-Sheraton Hotel, Pittsburgh.
1958	
Feb. 16-20	AIME Annual Meeting, Hotels Statler and Sheraton-McAlpin, New York.
Mar. 17-21	EJC Third Nuclear Engineering and Science Congress, Chicago.
Mar. 27-29	AIME Pacific Southwest Conference, St. Francis Hotel, San Francisco.
Apr. 14-16	AIME 41st Open Hearth Steel and Blast Furnace, Coke Oven, and Raw Materials Conference, Statler Hotel, Cleveland.
Apr. 17-19	AIME Pacific Northwest Regional Conference, Spokane, Washington.
May 5-6	AIME Conference on Properties of High Strength Steels. Sponsored by Iron and Steel Division in cooperation with Institute of Metals Division. Penn-Sheraton Hotel, Pittsburgh.
May 12-16	Southwestern Metal Exposition and Congress, Statler-Hilton Hotel, Dallas.
May 27-29	AIME Third Reactive Metals Conference, Statler Hotel, Buffalo.
Sept. 17-19	AIME Rocky Mountain Minerals Conference, Newhouse Hotel, Salt Lake City.
Oct. 27-31	AIME IMD Fall Meeting, Carter Hotel, Cleveland

GENERAL INFORMATION

A. Wilson of the Oriental Institute, University of Chicago. His topic is: "Five Thousand Years of Modern Egypt."

National Metal Congress and Exposition: The Fall Meeting of the Institute of Metals Div., AIME, is part of the Annual National Metal Congress.

The American Society for Metals has its headquarters at the Palmer House. The annual ASM Seminar will be held on Saturday and Sunday, November 2-3, immediately preceding the opening of the National Metal Exposition. The Seminar will be at the Palmer House, where all of the ASM Technical Sessions will be held this year. The subject of the Seminar will be "Liquid Metals and Solidification."

The ASM Campbell Memorial Lecturer will be Earl R. Parker, Professor of Metallurgy, University of California, who will speak Wednesday morning in the Ballroom of the Palmer House. His subject is: "Modern Concepts of Flow and Fracture." Also of special interest will be the two-day Conference on Platinum Metal, November 4 and 5, jointly sponsored by the Atomic Energy Commission and ASM.

In addition to the regular technical sessions of AIME, ASM, and the Society for Nondestructive Testing, a number of seminars are being held as part of the Second World Metallurgical Congress. Among the topic headings are: (a) Heat Treatment—"Carburizing," "Minimizing Distortion"; (b) Welding and Joining—"Ship Welding," "Electrodes," "Stress Relieving and Preheating"; (c) Metal Fabrication—"Steel Gears," "Selection of Sheet Steel for Formability," "Machining of Steel"; (d) Non-Ferrous Metals—"Continuous Casting," "Metal Degassing"; (e) Steelmaking and Refining—"Iron," "Steelmaking," "Solidification of Steel"; and (f) Inspection and Testing—"Testing in Product Development," "Testing for Quality Control after Product Development."

The National Metal Exposition is being held at the International Amphitheatre in Chicago during the week of November 4. The Exposition will be open from noon until 10:30 pm on Monday, Tuesday, and Wednesday, and from 10:00 am to 6:00 pm on Thursday and Friday. Between 450 and 500 nationally known firms engaged in the production of metals, the treatment of metals, the fabrication of metals, or those firms rendering services to such companies, will exhibit their products, equipment, and services.

SUNDAY, NOVEMBER 3

3:00 to 9:00 pm, First Floor Foyer

REGISTRATION

11:00 am, Parlor C

IMD COMMITTEE ON SCOPE OF TECHNICAL COMMITTEES
J. H. Jackson, Chairman

2:00 pm, Parlor B

IMD PROGRAMS COMMITTEE MEETING
R. L. Smith, Chairman

4:30 pm, Parlor C

IMD PUBLICATIONS COMMITTEE MEETING
C. E. Birchenall, Chairman

5:45 pm, Mexican Room, Normandy House (800 North Michigan Avenue)

THE METALLURGICAL SOCIETY, COMMITTEE ON THE METALLURGICAL PROFESSION
Morris Cohen, Chairman

MONDAY NOVEMBER 4

8:00 am, Parlor B

BREAKFAST FOR MONDAY SESSION CHAIRMEN AND AUTHORS

8:00 am to 4:00 pm, First Floor Foyer

REGISTRATION

9:00 am to 12:00 m, Grand Ballroom

SYMPOSIUM ON THE RELATION OF STRUCTURE AND HIGH-TEMPERATURE PROPERTIES
N. J. Grant and T. H. Hazlett, Chairmen

Nature of Aging of Iron-Chromium Alloys at 500° C: M. J. Marcinkowski and R. M. Fisher, United States Steel Corp.

The drastic changes in properties that occur in iron-chromium alloys containing 15-80 pct chromium during aging in the vicinity of 500° C have been the subject of considerable investigation during recent years. This paper reviews the large volume of experimental work that has been carried out in the last five years and discusses the two seemingly divergent hypotheses that have emerged.

One group of investigators holds that the iron-chromium phase

equilibrium requires the decomposition of ferrite or sigma into an iron-rich and chromium-rich ferrite during aging at 500° C. This idea has received its strongest support from the discovery of a non-magnetic body-centered cubic precipitate formed during heating at 475° C which appears to contain about 75 pct chromium. On the other hand, the initial increase in Curie temperature, magnetization and hardness, along with the decrease in electrical resistivity, appear to be best explained in terms of an ordering transformation. The rather wide temperature interval over which the transformation occurs (450–540° C) as substantiated by specific heat data give further support to the ordering hypothesis. One laboratory has reported observing superlattice reflections by X-ray diffraction, whereas several others have reported lack of success using both X-ray and neutron diffraction techniques. The results of new experiments designed to check both hypotheses are described with results of investigation of the changes in slip mechanism during aging.

Influence of Structures in Low-Alloyed Steels on the High-Temperature Properties: L. Habraken, Centre National de Recherches Metallurgiques, Liege, Belgium.

Using intensive electron metallography and X-ray diffraction on metals and residues of electrolytic extraction, structures obtainable in low-alloyed Cr-Mo and Cr-Mo-W-V steels with low carbon contents have been investigated in detail. After the study of the TTT curves of the steels in view to know the nature of the structure, heat treatments to produce, when it is possible, structural hardening have been applied. The creep properties of the different structures have been tested to 600° C. The evolution of the structures have been followed. Comparison of the results shows that structural hardening generally gives the best results; however, in practice this condition is not easy to realize.

Evolution of Aging Structures During High-Temperature Exposure: W. C. Hagel and H. J. Beattie, Jr., General Electric Co.

Systematic studies were conducted of progressive changes in the phase relationships and interrelated mechanical properties of many commercial nickel- and cobalt-base high-temperature alloys. Exposure temperatures varied from 1200 to 2250° F (650 to 1205° C) in 100-degree intervals for times up to, and occasionally beyond, 1000 hours. After taking hardness and impact-resistance measurements, light and electron microstructures were examined, and X-ray and electron diffraction phase identifications were made.

The results include electron-microscope temperature-time sequences of the size distribution of precipitation-hardening phases, evidence for the embrittlement of nickel-base alloys by the cellular precipitation of carbide rods, beneficial effects of multiple-aging treatments, complex carbide reactions and relative stability of other intermetallic compounds, the effect of vacuum melting and minor compositional variations on phase relationships, and the crystal structure of a new double boride obtained by adding an excess of boron.

Phase Changes in an Age-Hardenable Nickel-Iron-Chromium Alloy During Prolonged Heating: C. C. Clark and J. S. Iwanski, International Nickel Co.

X-ray diffraction and electron microscopic studies of Incoloy 901 revealed the presence of Laves phase in the grain boundaries. Precipitation at 1350° F appeared to be nearly complete after less than 2000 hours. During this time the gamma prime (Ni_3Al type) enlarged and began to transform to eta phase (Ni_3Ti). After about 7300 hours very little gamma prime phase remained in the microstructure but appreciable quantities of eta phase were present in a Widmanstatten pattern. Creep-rupture results are included to show that ductility at rupture is not impaired by the presence of the grain boundary Laves phase or by the Widmanstatten precipitate. Electron micrographs also are included of the material after more than 10,000 hours at 1000° and 1200° F.

Structure and Property Studies in Ni-Cr-Al Solid Solution Dispersion Hardened by Ni_3Al: J. H. Westbrook, General Electric Co.

Many of the leading nickel-base high-temperature alloys depend for their strength on dispersions of the compound Ni_3Al. Since these are all relatively complex alloys, it is difficult to assess the effects of composition, heat treatment and processing variables in terms of parameters pertinent solely to the dispersion hardening if Ni_3Al and independent of the effects of other compounds, solid solution hardening, etc.

It is apparent that what is needed are studies of simplified or prototype systems where factors leading to such ambiguities are eliminated or reduced. The Ni-Cr-Al system is perhaps the simplest system that approximates the successful complex commercial alloys. Previous structures and property studies on this system are limited to the phase diagram determinations by Taylor and Floyd and Kornilov and Minin, the exploratory investigations of Guy and limited stress rupture studies by Nordheim and Grant.

In the present study the structures, properties, and their interrelation in Ni-Cr-Al alloys in the nickel solid solution + Ni_3Al phase field have been examined in some detail. With respect to properties, observations are made on hot tensile strength, stress-rupture, hot hardness, and bend ductility; structural studies have included investigation of the nature of the dispersion, nucleation sites, stability, morphology, kinetics, and particle-matrix orientation.

Electron Microstructure of an Age-Hardenable Nickel-Chromium Alloy: K. G. Carrol and J. R. Mihalisin, International Nickel Co.

Electron microscope techniques are applied to delineate structural changes occurring in Inconel X at high temperatures. X-ray and electron diffraction are utilized for phase identification of particular microstructural constituents. Examples are shown of precipitation of grain boundary carbide in two distinctly different modes characteristic of different temperatures. Growth of the Ni_3Al (gamma prime) phase is studied through the use of Fisher's extraction replica technique, as well as through conventional replication for electron microscopy.

The kinetics of the precipitation reactions are discussed. In particular, similarities are noted between carbide formation in high-temperature alloys and in complex steels that exhibit double-nosed isothermal transformation curves.

Fundamental Influence of Cobalt in Heat-Resisting Steels: W. Siegfried, W. Bollman, B. Lux, and H. Nohl, Battelle Memorial Institute, Geneva, Switzerland.

The most important practical refractory alloys on the cobalt- and nickel-base are surveyed and critically analyzed. Creep tests on Cr-Ni-Co-Mo-W-alloys having a systematically varied cobalt content were run. The influence of the cobalt content in the different stages of creep was determined. Research on the fundamental mechanism of creep of these different alloys with the electron microscope by transmission and with X-rays is described.

9:00 am to 12:00 m, Constitution Room

SEMINAR ON STRUCTURE OF SOLID SOLUTIONS

B. L. Averbach and A. S. Nowick, Chairmen

Elastic Constants of Solid Solutions: Charles S. Smith, Case Institute of Technology.

Resistance Anomalies in Dilute Alloys: R. W. Schmitt, General Electric Co.

MONDAY, NOVEMBER 4

Nuclear Magnetic Resonance in Metals and Alloys: T. J. Rowland, Electro Metallurgical Co., Div. of Union Carbide Corp.

9:00 am to 12:00 m, Cotillion Room

DEFORMATION
N. H. Polakowski and E. J. Ripling, Chairmen

Effect of Deformation and Low Temperatures on the Structures of AgCd and AuZn: D. B. Masson and C. S. Barrett, University of Chicago.

Martensitic transformations have been found in AgCd both upon cold working at room temperature and upon cooling to lower temperatures; the crystal structures resulting from transformation have been solved by powder diffraction techniques using low-temperature diffractometers. The phase resulting from cold working the body-centered cubic phase AgCd is close-packed hexagonal with $c = 4.8279 \pm 0.0003$ Å, $a = 2.9710 \pm 0.0001$ Å, $c/a = 1.6250$ at 25° C. The phase induced by simple cooling yielded 33 lines; these were all well accounted for by an orthorhombic structure; space group D_{2h}^{17}—Cmcm, $a = 3.116 \pm 0.002$ Å, $b = 4.890 \pm 0.005$ Å $c = 4.779 \pm 0.005$ Å, at −196° C. 4 atoms per cell in the positions having the parameter $y = 0.195$. Transformation of a 52 pct Ag alloy begins on cooling below 127° K and reaches completion at 109° K; reversion to cubic begins at 124° K and reaches completion at 135° K. The transformation induced by cold work is also substantially complete. Similar treatments of AuZn of about 50 atom pct composition failed to induce a transformation.

Role of Rate-History in the Calculation of Creep Behavior: J. D. Lubahn, General Electric Co.

Temperature Dependence of the Yield Stress for Copper and Aluminum: W. D. Sylwestrowicz, Bell Telephone Laboratories.

Establishment of a fundamental relation between an applied load and deformation of metals has been attempted by many investigators. In the most simple form this relation is presented as a stress-strain curve in tension. The popularity of this form of presentation is due partly to the greater ease of performing experiments and partly to the comparatively simple interpretation of the data obtained. In turn it suggests the acceptance of strain as synonymous with the deformation. Eventually an equation of state was proposed where stress is taken as a function of strain, rate of straining, and temperature. Experimental evidence has since been presented showing the dependence of the stress-strain relation on the previous history of the specimen. Such dependence cannot be accounted for in this equation of state.

While the equation of state relating stress to strain has to be modified, it now appears that at temperatures where no recrystallization, change or appearance of new phase occur, a unique relation still may exist between yield stress and the plastic behavior of metals: a metal of a given yield stress should have subsequent properties independent of its previous history. In other words, two specimens deformed by different paths to the same yield stress should have at the same temperature the same rate of work hardening for the same rate of straining and, in the case of change of temperature, should have the same rise or drop of the yield stress.

Grain Boundary Deformation in Fine-Grained Electrolytic Magnesium: S. L. Couling, The Dow Chemical Co., and C. S. Roberts, Shockley Semiconductors Laboratory. (JOURNAL OF METALS, October 1957)

The relative contribution of grain boundary deformation to high temperature—low strain rate creep of electrolytic magnesium has been measured using a grid technique. Boundary deformation was found to be diffusion dependent and highly strain contributive, accounting for 67-93 pct of the total strain in the various specimens. A mechanism for the cyclic boundary shearing process is presented.

Activation Energies for Creep of Single Aluminum Crystals Favorably Oriented for (111)[101] Slip: J. Lytton, L. Shepard, and J. E. Dorn, University of California.

Single aluminum crystals were subjected to creep in simple shear on the (111) planes in the slip direction. The activation energies for creep were calculated from the effect of small abrupt changes in temperature on the creep rate just before and immediately following the temperature change, using the Arrhenius equation relating reaction rates to the absolute temperature. The results definitely establish the fact that creep of single aluminum crystals occurs by three unique processes characterized by three distinct and isolatable activation energies; the 35,500 cal. per mole activation energy obtained at the highest temperature was ascribed to a dislocation climb process; the 28,000 cal. per mole activation energy process occurring over the intermediate temperature range is believed to be due to control of the creep rate by a cross-slip mechanism; the 3,400 cal. per mole process was identified with easy glide; but the insensitivity of this activation energy to the stress prevented immediate acceptance of a dislocation intersection process as the controlling mechanism for this creep process.

Size Effects in the Deformation of Aluminum—Part I: Bicrystals; Part II: Single Crystals: R. L. Fleischer and Bruce Chalmers, Harvard University.

In order to observe size effects associated with a grain boundary, aluminum single crystal and bicrystals of various cross sectional dimensions were deformed in tension. Typical stress-strain curves are presented in conjunction with measurements of the effects of changes in crystal dimensions. Some effects of the growth rate used in preparation of crystals are also described. It is indicated that the macroscopic constraints at a grain boundary are responsible for the most sizeable grain boundary effect: the production of multiple slip. Two measurements of the width of the region of double slip are in agreement.

A discussion is presented of the size effects observed in the deformation of aluminum single crystals of varying cross sectional dimensions. It is concluded that the yield stress of aluminum is markedly affected by the inherent oxide coating. It is indicated that other properties of the stress-strain curves are interpretable by considering in some detail the stress in a tensile sample that is deforming. Some effects of growth rate used in preparation of the samples are also considered.

Abrupt Yielding and the Ductile-to-Brittle Transition in Body-Centered Cubic Metals: E. T. Wessel, Westinghouse Electric Corp. (JOURNAL OF METALS, July 1957)

The relationship of brittle fracture to the early stages of plastic deformation, particularly pronounced yielding, was examined in detail. Both abrupt yielding and brittle fracture are preceded by appreciable amounts of nonelastic strain. Abrupt yielding and the transition from a ductile-to-brittle behavior are shown to be closely related to one another and to a common origin. A mechanism for abrupt yielding and the ductile-to-brittle transition which is in good agreement with experimental data is presented.

Effect of Strain and Temper Embrittlement on the Impact Transition Temperature of an AISI E-6150 Steel: E. F. Steeb, North American Aviation, and P. C. Rosenthal, University of Wisconsin.

Charpy V-notch impact tests were conducted to determine the combined effect of tensile strain and temper embrittlement on the

transition temperature of an AISI E-8150 steel. Groups of specimens were strained various amounts (5.0 pct. maximum at room temperature or at 482° C [900° F]) either before or after the temper embrittling heat treatment. Also, for comparative purposes, some series of specimens were subjected to only the straining or temper embrittling treatment.

The combined effects of straining and temper embrittling suggest that temper brittleness is caused by concentration of solute atoms at prior austenite grain boundaries, the resulting localized stresses accounting for the embrittlement. By providing additional sites for this atom concentration through strain and subsequent annealing effects, a slight reduction in the impact transition temperature is realized.

9:00 am to 12:00 m, Embassy Room

STRUCTURES AND PROPERTIES OF METALS AND ALLOYS

(Session Based on Submission of Research Abstracts.)

W. D. Robertson and H. G. F. Wilsdorf, Chairmen

Preferred Orientations in Castings: Derek Walton and Bruce Chalmers, Harvard University.

A preference for a particular crystallographic axis in the long direction of the columnar grains in castings has long been known to exist. It has been shown that a sufficient condition for the production of this preferred orientation is the presence of dendritic growth during all or part of the solidification process. The preferred orientation is produced by the selective elimination of grains whose orientations are unfavorable; the object, therefore, of the experimental work was to observe the effect of the interface morphology on the change in grain size during solidification. Lead bicrystals were frozen in a horizontal boat. Provision was made for decanting so that the solid-liquid interface might be studied. The change in relative size of the crystals was then correlated with the interface structure. When the interface was dendritic, grain boundary deviation occurred that would result in an increase in cross section of grains whose ⟨100⟩ directions were closest to the heat flow axis. When the interface was cellular, grain boundary deviation was not observed. When the interface was plane, erratic grain boundary deviation occurred, but in no case was this deviation so large that the angle between the boundary and the normal to the interface exceeded 5°.

Experiments performed on castings of lead and aluminum to determine the effect of the casting variables showed that a preferred orientation only developed if the conditions under which solidification occurred were favorable to dendritic growth. Decanting the liquid metal during freezing confirmed that under conditions favorable to the production of a preferred orientation dendritic growth was observed while under unfavorable conditions dendritic growth was not observed. It has been observed that a favorably oriented grain encroaches on a less favorably oriented neighbor by the lateral growth of dendrite branches. When dendritic growth was suppressed to the point where branching did not occur, no encroachment was observed.

Ductility in Beryllium Related to Grain Orientation and Grain Size: J. Greenspan, Nuclear Metals, Inc.

The brittleness and ductility of the beryllium single crystal or its anisotropy of fracture and slip is characteristic also of polycrystalline beryllium in which the grains are oriented in a preferred manner. Beryllium with grain orientations resulting from hot working either uni-directionally or bi-directionally is ductile or brittle in directions given by the anisotropy and orientation of the grains. Textures developed from various hot-working sequences are given, and tensile results are correlated with textures.

Not only texture, but fine grain size is necessary for obtaining

high tensile elongation. Ultimate tensile strength and elongation are both correlated with grain diameter. Of particular interest is the case in which unusually high tensile elongations of 30 to 40 pct are obtained when basal planes are oriented to carry little or no tensile stress.

Effects of Various Preferred Orientations on the Dimensional Stability of Uranium: W. V. Cummings, General Electric Co.

It has been determined experimentally that the deformation of polycrystalline uranium resulting from dimensional instability during irradiation causes changes in preferred crystallographic orientation. X-ray diffraction studies of textures in cylindrical specimens before and after irradiation reveal definite changes in some diffracted line intensities. These variations in line intensity can be related to the radiation induced growth which in turn is dependent upon pre-irradiation crystallographic conditions. In agreement with other experimental data, a pre-irradiation preferred orientation in which the {010} poles are predominantly parallel to the cylindrical axis of the specimen resulted in an increase in length and a decrease in diameter. In general, the {010} texture increased slightly during the irradiation. A duplex {100}⟨110⟩ preferred alignment of the crystallites produced a decrease in length and an increase in diameter. An X-ray diffraction study of the irradiated metal revealed gross crystallite rotations as evidenced by a decrease in the {100} intensities and an increase in the {110} intensities. Material exhibiting a pre-irradiation {010}⟨110⟩ duplex preferred orientation showed a number of effects upon post-irradiation examination. The observed effects were found to be dependent upon the ratio of the magnitudes of the two textures. As the ratio of the {010} to the {110} textures increased, the growth in length of the specimens varied from minus a few per cent to plus 85 per cent. Growth was found to be zero at a ratio of about 0.25. Deformation could also be stated to be zero since essentially no surface roughening occurred. Changes in diffracted line intensities were observed for specimens with specific types of crystallographic orientation other than those mentioned previously.

Dimensional Stability of Uranium-Chromium Alloys: M. C. Fraser, G. A. Last, and S. H. Bush, General Electric Co.

The influence of alloy concentration on the irradiation induced dimensional changes in the uranium-chromium system has been determined at low chromium concentrations bridging the solid solution range. Uranium specimens containing 0 – 1 atomic pct of chromium and fabricated to develop a definite preferred orientation were irradiated. Variables controlled were: alloy content, grain size, type and degree of preferred orientation, and atom burnup.

Post-irradiation examination of the specimens revealed definite longitudinal growth accompanied by warping and some surface striation. A comparison of the pct of growth as a function of alloy concentration did not reveal any marked alloy effect. There was no indication that the chromium had a beneficial or deleterious effect on the growth which ranged from 2 to 17 per cent.

A Study of the Effect of Reactor Irradiation on the Microstructure of Uranium: T. K. Bierlein and B. Mastel, General Electric Co.

The microstructure of annealed, beta heat-treated uranium irradiated in the Materials Testing Reactor has been studied by special techniques. Prior to irradiation, metallographic specimens were etched by ion bombardment, replicated with cellulose acetate, and then sealed in Zircaloy-2 capsules containing NaK as a heat transfer medium. After irradiation to approximate burnups of 0.03, 0.07, and 0.1 pct, respectively, the specimens were replicated again. Identical areas in the replicas corresponding to the pre- and post-irradiation states were isolated and examined by both optical and electron microscope techniques. In general, very little change in the microstructure was detected, either in the as-irradiated or the as-irradiated and re-etched states. However, optical microscopic examination has revealed direct evidence of

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twin formation and twin growth as a result of the irradiation. In addition, electron microscope examination of random areas in replicas of the irradiated specimens has disclosed microcracks and twin and grain boundary segregation which have not been observed in control specimens. The results of hardness, density, and X-ray line breadth measurements are briefly discussed in relation to the observed microstructure.

Irradiation Effects on the Tensile Properties of Zircaloy-2: R. S. Kemper, Jr., and D. L. Zimmerman, General Electric Co.

The changes produced in the tensile properties of annealed and cold-worked Zircaloy-2 as a result of irradiation to an integrated thermal neutron flux of 1.4×10^{21} nvt at 40 to 60° C have been determined. Recovery of irradiation damage in initially annealed material was studied in the temperature range 250 to 400° C. The room temperature tensile behavior of annealed Zircaloy-2 was altered by irradiation in the following ways: (1) a yield point with slight drop in load was developed, (2) the yield strength was increased 80 per cent, (3) the flow curve after yielding exhibited a region of low work-hardening and the work-hardening coefficient determined from the slope of the $\log_{10}$ true stress-$\log_{10}$ true strain curve was lowered to nearly the same value as that for cold-worked material, (4) the ultimate strength was increased 17 per cent, and (5) the total elongation was reduced approximately 35 per cent.

Material cold-worked to 50 per cent reduction in area by swaging prior to irradiation did not develop a yield point, the yield strength was raised 30 per cent, the ultimate strength was increased 17 per cent, and the total elongation was reduced 51 per cent. The annealing studies indicated that the yield point developed by irradiation could be removed by annealing at 300° C although appreciable recovery, as measured by yield strength reduction, required higher temperatures. The activation energy for the latter recovery was found to be consistent with that reported for self-diffusion in zirconium.

Brittleness and the Thermal Expansion Behavior of Titanium Carbide Base Cermets: H. W. Newkirk, Jr., General Electric Co., and H. H. Sisler, Ohio State University.

The crystal structure and thermal expansion of titanium carbide, nickel and Kentanium cermets, designated K-151-A and K-152-B, were determined between room temperature and 1100° C (2012° F). No structural changes were observed. An abnormal rate of expansion was observed for pure nickel near the Curie temperature 353° C (667° F) and for the nickel and carbide phases in the cermets about 816° C (1500° F). The expansion coefficient of pure nickel and the nickel phase in the cermets was found to be approximately twice that of pure titanium carbide and the carbide phase in the cermets. The brittleness and poor impact strength of the cermets was attributed to the large residual stresses present in these materials as a result of this difference in thermal expansion. The stress-strain relationships were interpreted as the basis of a mechanical interaction between the phases in the cermets. The carbide phase was found to be essentially under triaxial compression and the metal phase under a triaxial tension of 158,000 psi. At elevated temperatures, increased solid solubility of carbide in the metal phase and plastic deformation of this phase is believed to influence the stress-strain relationships and the thermal expansion behavior of the phases. It was concluded that replacement of the metal phase in the cermets with a metallic alloy, such as a nickel-chromium-molybdenum alloy, which has a coefficient of thermal expansion similar to the carbide phase in the cermets, would improve the impact strength of these bodies. Equations have been developed for the thermal expansion of titanium carbide and nickel. These equations are represented respectively by:

$$\Delta l_{25}^{T} / l_{25} = 2.210 \times 10^{-5} + 4.611 \times 10^{-9} (T-C), \text{ and}$$

$$\Delta l_{25}^{T} / l_{25} = 4.126 \times 10^{-5} + 9.834 \times 10^{-9} (T-C)$$

Values of the expansion coefficient were computed for each of the materials by differentiation of the above equations. The high-temperature X-ray diffraction camera used is described.

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Estimation of Coefficients for the Reactive Diffusion of Carbon in Zirconium Carbide: E. Hirakis and M. A. Steinberg, Horizons, Inc.

Zirconium carbide reaction layers were produced on graphite specimens by firing in tin-zirconium alloy melts at temperatures in the range 1890/2160° C for periods of up to 4 hours.

The carbide coatings were evaluated metallographically. Film thickness was found to be 90 to 95 per reproducible.

Graphs of coating thickness as a function of exposure time at temperature indicate that the growth rate follows the parabolic law for coatings between 13 and 42 microns thick. The data further show that the growth rate is independent of binary tin-alloy composition between 2 and 26 wt. per zirconium.

The graphical method of J. J. Hermans was employed in the determination of the diffusion coefficients. In this connection an arbitrary assumption was made to the effect that at the reaction temperature the carbon concentration in the coating varies from 50 atomic per at the carbide-graphite phase boundary to 21.6 atomic per at the carbide-liquid alloy interface. These figures were obtained from the published data of G. V. Samsonov and N. S. Rostova. Diffusion coefficients for carbon in zirconium carbide at temperatures of 1500° and 2000° C were determined to be 4.3 $\times 10^{-9}$ and 5.6×10^{-8} cm^2/sec., respectively. Based on these constants, an activation energy of 25,800 kcal/mole was estimated. X-ray diffraction analysis of coated specimens from which the remnant tin-zirconium alloy had been removed by vacuum heat-treatment gave the characteristic ZrC pattern. The lattice parameter, a_o, was found to be 4.6906 AU, characteristic of stoichiometric zirconium carbide.

Surface Tension of Silver-Gold and Copper-Gold Solid Solutions: S. S. White, C. M. Adams, Jr., and J. Wulff, Massachusetts Institute of Technology.

A modification of the Udin, Shaler, and Wulff technique was used to determine the solid surface tensions of the systems silver-gold and copper-gold. The surface tension of the former was found to vary almost directly with bulk composition, exhibiting a slight positive deviation from linearity, the surface tension varying from 1140 dynes/cm. for pure silver to 1500 dynes/cm. for pure gold. The surface tension of copper-gold was found to vary parabolically with bulk composition, with a minimum of 980 dynes/cm. occurring at the 50-50 atomic composition, and a maximum value of 1650 dynes/cm. for pure copper. The Gibbs adsorption equation, as it applies to non-dilute solutions, is used in conjunction with existing activity data to evaluate excess surface concentration as a function of bulk composition. Re-expressing excess concentration in terms of surface compositions, subject to certain structural assumptions, the conclusion is reached that the "surface" of alloys of both systems is composed of at least two to four atomic layers. For all silver-gold alloys, silver was always in excess on the surface. For copper-gold alloys with less than 50 atomic per gold, gold was in excess on the surface; for those with more than 50 atomic per gold, copper was in excess on the surface.

In addition to surface tensions, viscosity data were also obtained; these indicate that, in the micro-creep range, viscosity is a continuous function of bulk composition. Qualitative observations on strain-induced ordering in copper-gold alloys have been made, and a sensitive technique for determination of the temperature of order-disorder reactions is suggested.

Autoradiographic and Metallographic Evidence for a Metallic Second Phase in High-Purity Zinc: I. S. Servi, M. Stern, and W. W. Webb, Electro Metallurgical Co., Div. of Union Carbide Corp.

During attempts to study impurity segregation at dislocation walls in zinc, it was found by autoradiographic techniques that additions of 10^{-10} atom fraction polonium-210 in zinc of 99.999 per purity segregate into a regular pattern of clusters containing 100 to 10,000 polonium atoms. Metallographic examination revealed isolated particles or clusters of particles of a second phase with particle diameters ranging from 500 to 3000 Å. This second

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phase, at which etch pits often nucleate, is attributed to lead even in alloys with a lead content below 1 ppm. The solubility of lead in zinc is estimated to be below 0.5 ppm from metallographic and autoradiographic evidence and an analysis of solidification segregation. It is suggested that published accounts dealing with those properties of zinc that could be affected by a finely dispersed second phase be reviewed in the light of this result.

12:00 m, Parlor C

IMD TITANIUM COMMITTEE LUNCHEON MEETING
L. S. Busch, Chairman

12:00 m, Parlor B

IMD CHEMISTRY AND PHYSICS OF METALS COMMITTEE LUNCHEON MEETING
J. C. Fisher, Chairman

2:00 to 5:00 pm, Grand Ballroom

SYMPOSIUM ON THE RELATION OF STRUCTURE AND HIGH-TEMPERATURE PROPERTIES
J. H. Bechtold and F. M. Richmond, Chairmen

Influence of Carbon and Nitrogen on Creep and Creep-Rupture Properties and Structure of 18 Cr-8 Ni and 18 Cr-8 Ni Mo Steels: G. V. Smith, Cornell University, F. Garofalo and L. Zwell, United States Steel Corp.

Examination of the elevated temperature properties of low-carbon (0.03 pct max.) grades of austenitic stainless steels has shown that their strengths are appreciably lower than those of the normal-carbon grades. Although it has been shown that an improvement in creep and creep-rupture strength is found by increasing the carbon or nitrogen content, a more extensive examination of the structures developed at elevated temperatures has been lacking. Information on the combined influence of carbon and nitrogen on high-temperature properties has also been lacking.

In the present study, the influence of both carbon and nitrogen, singly and in combination, on creep and creep-rupture properties and on structure has been examined. Experimental evidence of this type has been obtained for two austenitic stainless steels, AISI Types 304 (18 Cr-8 Ni) and 316 (18 Cr-8 Ni-Mo). The carbon content varied between 0.06 and 0.16 pct by weight and the nitrogen varied between 0.03 and 0.22 pct. Creep and creep-rupture results were obtained at 1100, 1300 and 1500° F. Examination of the structures developed at 1300 and 1500° F was made by the usual metallographic and X-ray techniques.

The experimental findings indicate for these steels that the hardness, yield strength, and tensile strength at room temperature increased with increasing carbon and/or nitrogen, whereas ductility decreased slightly. Creep and creep-rupture strength increased with increasing carbon plus nitrogen, except at 1500° F. Strength properties at 1100° F are sensitive to annealing temperatures; this effect is relatively unimportant at 1300 or 1500° F.

Microstructural changes during test were very extensive. No sigma or chi could be detected microscopically in the 18 Cr-8 Ni steels. The 18 Cr-8 Ni-Mo steels contained one or both phases. X-ray evidence on samples tested at 1500° F indicates the existence of sigma, alpha iron, complex carbides and nitrides in the 18 Cr-8 Ni steels. In addition to these phases, chi phase was observed in the 18 Cr-8 Ni-Mo steels. X-ray results on samples cold deformed at room temperature and exposed at 1300° F for 3000 hours substantiated the results obtained on the samples tested at 1500° F.

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Effect of Interstitial Elements on the Properties of Cr-Mn-N-C Steels: Chi-Mei Hsiao and E. J. Dulis, Crucible Steel Co. of America.

A study of microstructural changes in a 42 pct Ni-30 pct Cr-25 pct Fe alloy was made after creep and rupture testing at 1400, 1600 and 1800° F for test periods up to 10,000 hours. Identification of phase transformations was made by optical metallography and X-ray diffraction. The alloy was tested in two conditions, mill annealed and grain coarsened. The alloy when in the mill-annealed condition exhibits the peculiar behavior of having greater creep and rupture at 1800° F than at 1600° F for time periods beyond 1000 hours. The 42 pct Ni-30 pct Cr-25 pct Fe alloy is primarily of a structure and is non-magnetic as put into test. Magnetic anomalies were observed after exposure to stress and elevated temperatures. Oxygen and nitrogen pickup from the air resulted in the formation of chromium nitrides, internal oxidation, and depletion of chromium from the matrix. Creep and rupture data are reported.

Microstructural Changes in a 42 Per Cent Ni-30 Per Cent Cr-25 Per Cent Fe Alloy During Creep-Rupture Testing: E. P. Sadowski and R. J. Raudebaugh, International Nickel Co.

The effect of interstitial elements and precipitation reactions on the room- and elevated-temperature mechanical properties has been investigated in austenitic Cr-Mn-C-N stainless steels. These steels are supersaturated solid solutions in the solution-treated condition, and when they are reheated below the solvus temperatures (either by prior heat treatment or during service at elevated temperature), precipitation reactions take place. In the solution-treated condition, the strengthening effects of C and N on the room- and elevated-temperature tensile properties have been established. This strengthening is related to the valence effects of the interstitial solid solution of C and N. The analyses of the effects of the interstitial solid solution elements on creep-rupture properties is complicated by the influence of the factor time at temperature. During the relatively long-time exposures at the test temperatures, the interstitial elements form compounds by precipitation reactions and the morphology and distribution of these compounds have a marked effect on properties.

The effects of the following two types of precipitation reactions on the room- and elevated-temperature properties have been investigated: (1) grain-boundary reaction (characterized by the formation of lamellar nodules at grain boundaries), and (2) general precipitation (characterized by a Widmanstätten structure). In general, it has been found that the grain-boundary reaction is detrimental to the creep-rupture strength and the general precipitation is beneficial. The compositions of austenitic Cr-Mn-C-N stainless steels, and possibly other alloys containing interstitial elements, could be designed based upon the principles established in this investigation.

Nickel-Chromium Base Alloys Hardened with Refractory Oxide Additions: A. W. Cochardt, Westinghouse Electric Corp.

Nichrome powder was mixed with fine powders of alumina, titania, or silica, the oxide content ranging from 0.5 to 5 pct. The mixtures were cold-pressed and sintered and were then extruded, hot-rolled or forged. Stress-rupture properties at 1600° F and hardness values were determined. It was found that, in all cases, additions of an oxide decreased the time to rupture. This observation appears to be due to the formation of void layers around the oxide particles. A mechanism is suggested, according to which an incoherent particle does not strengthen the matrix alloy if the surface energy between particle and matrix is greater than the surface energy of the matrix itself.

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Contribution of Spherical and Platelike Precipitate Particles to Creep and Tensile Strength: E. E. Underwood, Battelle Memorial Institute.

Spherical and platelike precipitates were prepared in aluminum alloys with 1 to 4 pct copper. The effects of controlled sizes and distributions were determined by creep, tensile, and hardness measurements; quantitative metallographic evaluation of the particle characteristics; and X-ray and electron microscope examinations. Single-phase strength curves, interpolated between high-temperature and room-temperature data, give the strength of the alloy matrix, which is then subtracted from the measured strength of the particle alloy. The difference is thus a measure of the contribution of the particles to the strength of the alloy.

Up to a critical particle spacing, at low and high stresses, alloys with finer spacings are stronger than those with coarse; at intermediate stresses the alloys with coarse spacings are stronger. Beyond the critical spacings of about 50μ, the strengthening due to spherical particles increases to a large value before tapering off at a spacing of about 750μ. The same shape of curve is obtained with room temperature tensile strengths as with minimum creep rates, in spite of the fact that profuse stress-induced precipitation occurs during the creep tests. The importance of the matrix composition to alloy strength is shown. Precipitation during the test does not necessarily increase the strength of a two-phase alloy above that of a single-phase alloy with the same overall composition.

Creep and Structure Studies of Two-Phase Aluminum Copper Alloys: R. Pelloux, A. R. Chaudhuri, and N. J. Grant, Massachusetts Institute of Technology.

In two aluminum–copper alloys containing respectively 2.05 and 3.02 pct copper, the effects of the distribution and the size of the second phase were studied in connection with the strength mechanisms of deformation and fracture of the alloys during creep at 500 and 700° F.

For this program, two types of distribution of the second phase were studied at each temperature. Thus all four structures were overaged; however, there was a significant difference in the particle size and distribution, which resulted in marked changes in ductility and fracture, but only small changes in strength. Comparison is also made with an initially underaged structure for the 2.05 pct copper alloy.

2:00 to 5:00 pm, Constitution Room

RESEARCH SUMMARIES ON STRUCTURE OF SOLID SOLUTIONS
(Session Based on Submission of Research Abstracts.)
J. C. Fisher and C. A. Wert, Chairmen

Solubility of Hydrogen in Thorium Metal: D. T. Peterson and D. G. Westlake, Iowa State College.

Solubility of hydrogen in thorium metal from room temperature to 800° C was measured. This solubility information was obtained as part of an investigation of the rate of diffusion of hydrogen in thorium and the effect of hydrogen on the physical properties of thorium metal. The measurements were made by saturating samples of the metal in a Sieverts apparatus and analyzing by warm extraction at 800° C. Crystal-bar thorium and calcium-reduced thorium were used in these experiments and small solubility differences between them were observed. The cause of these solubility differences is still under investigation and has been tentatively assigned to the impurity levels in the two types of metal. The logarithm of the solubility gave a linear plot against the reciprocal temperature in each case. The microstructures of the saturated samples were examined to verify the homogeneous and uniform distribution of hydrogen and to determine the form which the hydride precipitates on quenching. The thorium hydride tends to precipitate as stringers along grain boundaries and can be identified by metallographic examination. The absorption of hydrogen by the metal samples has an induction period which varies with the temperature. The hydride tends to penetrate more rapidly along grain boundaries than through the bulk of the metal. These observations indicate that the rate of absorption may be limited by a reaction of the metal-hydride interface, rather than by the rate of diffusion through a thorium hydride coating.

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Free Energy Changes Attending the Martensitic Transformation in the Fe-Cr and Fe-Cr-Ni Systems: Larry Kaufman, Lincoln Laboratory, Massachusetts Institute of Technology.

Recent Russian work on the thermodynamics of the α-γ phase equilibrium in the iron-chromium system provides information necessary to derive the thermodynamic parameters associated with the energetics of the martensitic $\gamma \rightarrow \alpha'$ transformation in Fe–Cr alloys. Svechnikov and Lesnik derive values for $\Delta F_{Cr}^{\alpha \rightarrow \gamma}$ which fit Eq. (1)

$$\Delta F_{Cr}^{\alpha \rightarrow \gamma} = 460 \pm 1.0\ T\ ^{\circ}K\ \text{cal/mol} \qquad (1)$$

By using Eq. (1) and the regular solution approximation for Fe–Cr alloys it is possible to derive an equation for $\Delta F_{M}^{\alpha \rightarrow \gamma}$ (Fe–Cr), the difference in free energy of mixing between the α and γ phases in the Fe–Cr system. The results of this calculation can be used to explain the "anomalous" behavior of Fe–Cr alloys which seem to exhibit a γ-loop concurrent with a decreasing M_S for increasing chromium contents.

The present treatment in combination with earlier work on the Fe–Ni system is utilized to derive an equation for $\Delta F^{\alpha' \rightarrow \gamma}$ (Fe–Ni–Cr), the difference in free energy between the α' and γ phases in the Fe–Cr–Ni system. On the basis of the regular solution approximation

$$\Delta F^{\alpha' \rightarrow \gamma}_{(\text{Fe-Ni-Cr})} = x\Delta F_{Ni}^{\alpha \rightarrow \gamma} + y\Delta F_{Cr}^{\alpha \rightarrow \gamma} + z\Delta F_{Fe}^{\alpha \rightarrow \gamma} + xz(B-A)_{\text{Fe-Ni}} + yz(B-A)_{\text{Fe-Cr}} \qquad (2)$$

where x, y, and z are the atom fractions of Ni, Cr, and Fe. Explicit temperature dependent functions have been derived for the free energy differences in Eq. (2). The resultant equation for $\Delta F^{\alpha' \rightarrow \gamma}$(Fe–Ni–Cr) has been used to calculate the driving force at M_S in stainless steels of the same composition as those measured by Eichelman and Hull and Monkman, Cuff and Grant. The utilization of this treatment for calculating M_S and T_O (which lies above M_S) in low carbon stainless steels will be discussed.

Calculation of Entropies of Solute Atoms from Solid Solubilities: J. F. Freedman, Yale University, and A. S. Nowick, Watson Laboratories, International Business Machines Corp.

Such fundamental thermodynamic quantities as the change in enthalpy and the excess entropy when a given solute atom is dissolved in a pure solvent are of considerable interest with regard to questions of the theory of the constitutional diagram formed by a given pair of metals. These parameters are not readily attainable through direct thermodynamic measurements, but can be obtained from solubility data. For very dilute solutions (less than one atomic pct), the slope and intercept of a plot of the logarithm of solubility against the reciprocal absolute temperature are proportional to the enthalpy of solution and excess entropy respectively. When the solubilities are higher (up to 3 atomic pct), a modified equation has been derived

Applying this type of analysis, available solubility data are examined for simple systems in which two terminal solid solutions are separated by a two-phase region, and also for systems involving equilibrium between a terminal solution and a well-defined intermetallic compound. The intrinsic entropies (excess entropies per solute atom) obtained are compared with the theory of Zener and that of Huntington, Shirn and Wajda. All of the values for intrinsic entropy obtained from the available solubility data (with only one exception) turn out to be positive and similar in magnitude to the values derived for various lattice defects by Huntington and coworkers. It is also found that a quantitative interpretation of the entropy values obtained cannot be given entirely in terms of Zener's elastic strain theory but requires consideration of nearest-neighbor interactions.

Elastic Interaction of Interstitial Atoms in Body-Centered Cubic Crystals: J. C. Fisher, General Electric Co.

The elastic distortions near interstitial atoms in body-centered cubic crystals are estimated by an atomistic relaxation process. Through knowledge of the local strains, the elastic binding energy of a pair of interstitial atoms is calculated and is found to agree satisfactorily with Powers' experimental value of about 2 kcal/mole. In addition, the magnitude of the local strain produced by an interstitial atom is determined from the tetragonality of martensite to be approximately 0.19, and it is shown that the influence of carbon in increasing the free-energy of α-iron (relative to γ-iron of the same composition) is largely accounted for by elastic strain energy.

Misfit Strain Energy in the Gold-Copper System: Ralph Hultgren, University of California. (JOURNAL OF METALS, October 1957)

Misfit strain energy has been calculated for the AuCu lattice from interatomic distances and the Morse function; the calculations give results of the same order of magnitude as calculations from elasticity theory. It is shown that electronic rearrangements occur during uniaxial tension greatly reducing the strain energy from that calculated by ordinary methods. The theory of Pauling is applied and the electronic rearrangements derived from this theory reduce the strain energy to small values. This is not true, however, in other lattices. An explanation is advanced as to why gold-copper alloys form more exothermically than gold-silver alloys.

An Acoustical Study of Low Temperature Aging in Al-4.2 Cu: M. E. Fine and C. Chiou, Northwestern University.

After solution treating and during aging of Al-4.2 Cu at low temperatures the resonant frequency of a polycrystalline rod vibratin longitudinally increases with time about 0.2 pct. Information concerning the kinetics of age-hardening and formation of Guinier-Preston zones has been obtained by measuring this change. The increase in frequency is due to an increase in Young's modulus. The change in length and density may be neglected. The change in modulus is due presumably to a change in the distribution of atom bonds.

After solution treating by quenching in water from 510° C, aging was carried out at room temperature 0° C and 42° C. The time exponent in the rate equation is approximately 1/2, indicating that growth of the G. P. plates is not controlled by bulk diffusion. The $t^{\frac{1}{2}}$ law suggests line diffusion, for example, along a dislocation, as the time limiting process. The variation in rate with temperature corresponds to an activation energy of about 18 K Cal/Mole. Solution of the Cu was also accomplished by reversion at 206° after aging at room temperature. An incubation time is observed on re-aging which on the basis of preliminary measurements is smaller at room temperature than either at 42° C or 0° C. Further studies with single crystals are in progress.

Alloying Behavior of Ni_3Al (γ'-Phase): R. W. Guard and J. H. Westbrook, General Electric Co.

In many superior nickel-base high-temperature alloys the elevated temperature strength is attributable to the presence of a dispersion of Ni_3Al (γ') in a solid solution matrix. In order to improve our understanding of these materials the effects of alloying additions on the properties and equilibrium relationships of Ni_3Al have been considered. Several tests were made to establish whether there is any transformation present in Ni_3Al at high temperatures as has been proposed by several workers. No evidence was found in support of any crystallographic change between room temperature and 1000° C.

A survey of phase diagrams was made to determine the extent of the γ' region for ternary systems of Ni-Al-X where X is Fe, Co, Cu, Mn, Ti, Cr, Si, Zr, and Mo. Extensive solubility in Ni_3Al occurs for Fe, Co, Cu, Ti, Cr, and Si. In several of these cases the effect of alloying on the lattice parameter and hardness at room and elevated temperatures was investigated. The effect of deviations from stoichiometry in the binary Ni_3Al phase was also examined. In general, alloying additions and deviations from stoichiometry increase the hardness in a manner which is to be expected from the known rules of solid solution effects. The changes in lattice parameter are dependent on the relative size of the alloying atom and its position in the periodic table. The rules proposed for binary terminal solid solutions are obeyed satisfactorily. A discussion is presented of the stability of Ni_3Al with respect to neighboring phases and the extent of solubility.

2:00 to 5:00 pm, Cotillion Room

TITANIUM METALLURGY
D. W. Levinson and R. A. Perkins, Chairmen

Phase Transformations in Hypoeutectoid Titanium-Chromium Alloys: H. I. Aaronson, W. B. Triplett, and G. M. Andes, Carnegie Institute of Technology. (JOURNAL OF METALS, October 1957)

The nucleation of pearlite at proeutectoid ferrite is inhibited, to an increasing extent, at the following locations: at twin boundary-nucleated ferrite, between closely spaced ferrite sideplates and at intragranular plates. The growth of pearlite into the interiors of austenite grains from the region of the grain boundaries is markedly restricted when low reaction temperatures and large austenite grain sizes permit the development of interlocking networks of intragranular ferrite plates.

Notch Tensile Properties of Selected Titanium Alloys: E. P. Klier, Syracuse University, and N. J. Feola, Curtiss-Wright Corp. (JOURNAL OF METALS, October 1957)

Selected alpha, alpha-beta, and beta alloys have been tested in the notch-tension test. The base alloys were variously contaminated with carbon, nitrogen, and/or oxygen and the notch sensitivity of the resultant materials was determined in the temperature interval $-320 \leq T \leq 75°F$. From these results contamination limits to produce embrittlement at the testing temperatures examined have been established.

Effect of Hydrogen on the Fatigue Properties of Titanium and Ti-8Mn Alloy: L. W. Berger, W. S. Hyler, and R. I. Jaffee, Battelle Memorial Institute. (JOURNAL OF METALS, January 1958)

Hydrogen additions of 390 ppm to A-55 titanium and 368 ppm to Ti-8Mn have no deleterious effect on the unnotched and notched rotating-beam fatigue properties of these materials. These amounts of hydrogen, however, are sufficient to cause severe notch-impact embrittlement and pronounced loss of tensile ductility in Ti-8Mn. The lack of embrittling effect in fatigue in the

latter alloy is consistent with the postulated strain-aging mechanism of hydrogen embrittlement in alpha-beta alloys. There is a significant increase in the unnotched endurance limit of A-55 titanium with the addition of hydrogen. This increase may be explained as the result of internal heating effects that would dissolve the hydride and cause solid-solution strengthening.

Hydrogen Distribution in Heat-Treated Titanium Alloys as Established by Autoradiography: O. J. Huber, J. E. Gates, A. P. Young, M. Poberskin, and P. D. Frost, Battelle Memorial Institute. (JOURNAL OF METALS, July 1957)

The duplex heat-treatment of the two phase titanium alloys containing relatively large amounts of beta-stabilizing elements frequently produces a dark etching phase at the grain boundaries. An investigation of this phase was conducted on an alloy containing Ti-3 pct Mn-1 pct Fe-1 pct Cr-1 pct Mo-1 pct V in the annealed and in the heat-treated condition. Autoradiography, using tritium as a tracer element, and electron microscopy showed the intergranular phase to be hydrogen-rich material.

Hydrogen Solubility and Removal for Titanium and Titanium Alloys: W. M. Albrecht and M. W. Mallett, Battelle Memorial Institute.

The presence of hydrogen in titanium and titanium alloys has detrimental effects on the mechanical properties of the metal. The hydrogen content of commercial titanium is sometimes of the order of 200 ppm. by weight and varies with alloy composition. As a consequence, titanium and some titanium alloys as normally processed are sometimes not ductile unless treated to lower the hydrogen content. The best known hydrogen removal treatment is heating the material in a vacuum. The rate of removal (degassing) at a given time determines the duration of the treatment required to attain a satisfactory low hydrogen level. The partial pressure of hydrogen in the system during this treatment determines the lowest hydrogen content that can be obtained at equilibrium at the given temperature. The present investigation was made to determine the rates of degassing and the low-pressure, equilibrium solubility of hydrogen in titanium and its alloys. The temperature range 600 to 1000° C was investigated. Consideration was also given to an inert gas sweep method for the removal of hydrogen.

Effect of Crystallographic Orientation and Oxygen Content on Knoop Hardness Values of Iodide Titanium: C. Feng and C. Elbaum, University of Toronto. (JOURNAL OF METALS, January 1958)

Knoop hardness measurements were carried out on large grains of iodide titanium containing different amounts of oxygen. For each content the hardness is recorded as a function of the crystal orientation and of the angle ϕ between the indenter diagonal and the projection of the C (hexad) axis in the surface. The results can be expressed by the following relation:

$$\text{Hardness} = n - k \cos 2\phi$$

where n and k are constants for a given oxygen content and crystal surface orientation.

Effect of Hydrogen on Some Mechanical Properties of a Titanium Alloy Heat Treated to High Strength: H. A. Robinson, P. D. Frost, and W. M. Parris, Battelle Memorial Institute.

The effects of hydrogen content and strain rate on the static tensile and notch-rupture properties of the Ti-4Mn-complex alloy heat treated to different strength levels were investigated. The tensile test results indicated a decrease in ductility as the hydrogen content was increased from 25 to 280 ppm. for all strength levels tested. The loss of ductility was greater as the strength increased, reaching a maximum of 80 pct loss of tensile ductility at the 177,500 psi strength level as the hydrogen was increased from 25 to 140 ppm.

It should be noted that this latter hydrogen content is within the present specification maximum for titanium sheet.

With regard to the influence of testing speed, specimens containing 260 ppm. of hydrogen definitely indicated a decrease in ductility for decreasing strain rates. The results offer further support to the hypothesis that the mechanism of hydrogen embrittlement involves the diffusion of hydrogen to critical local areas. Stress rupture test results further indicated the effect of strain rate by showing embrittlement at somewhat lower hydrogen contents than had caused severe loss of tensile ductility. The most significant result of the stress-rupture tests was the absence of embrittlement for the solution treated condition at an intermediate strength level for all hydrogen levels evaluated. The high tolerance for hydrogen of the solution treated condition as well as the decreasing tolerance as the strength increased was correlated with the amount of retained beta in the microstructure. The higher tolerance of structures containing higher quantities of beta phase suggest that heat treatments should be carried out at the highest solution and aging temperatures to retain the greatest amount of beta phase, consistent with the desired strength and ductility.

Reorientation Texture Developed by Isothermally Annealing Cold-Rolled Iodide Titanium: C. J. Sparks, Jr., Wright Air Development Center, and J. P. Hammond, Oak Ridge National Laboratory.

Qualitative pole figures were plotted for the preferred orientation textures developed by annealing 94 pct cold-rolled iodide titanium at various times and temperatures. The isothermal anneals were for periods from 0.32 to 10,000 minutes and for temperatures from 260° to 850° C. In addition to complete pole figures for the {1010} and {0002} planes for various anneals, X-ray intensity traces were obtained from selected positions with respect to the rolled sheet. These traces provided a means for continuously following the preferred orientation changes resulting from annealing.

The deformation texture of titanium was found to undergo a sharpening on annealing to temperatures of 475°C. This "in situ" texture was found to sharpen at the expense of the material deviating by about 10° from the intensity maximum of the deformation texture. A spreading of the deformation texture begins at 475° C and this develops on further annealing into a texture related to the deformation texture by a rotation about the normal direction to the rolled surface. Both this texture and another texture related by a rotation about the C-axis to the deformation texture compete for growth. The final orientation developed by annealing at 850°C was a texture described by a 30° rotation about the C-axis.

The annealing textures are both time and temperature dependent. The gathering of the <0002> poles at a position 33° from the normal direction toward the cross direction is the strongest tendency of the texture on annealing with other intensity maxima being weakened or showing greater spread. Comparison is made with quantitative data on zirconium and titanium textures from other investigations. The results are discussed in terms of present theory on annealing textures.

2:00 to 5:00 pm, Embassy Room

DEFORMATION AND OXIDATION
(Session Based on Submission of Research Abstracts.)
B. D. Cullity and W. T. Chandler, Chairmen

Hydrogen, Crack Initiation, and Delayed Failure in Steel: H. H. Johnson, J. G. Morlet, and A. R. Troiano, Case Institute of Technology.

Crack initiation and delayed failure were investigated in high-strength steel containing a uniform hydrogen distribution. This distribution results from the cadmium electroplating and baking of electrolytically charged steel. The static fatigue limit decreased with both higher hydrogen concentrations and sharper notches.

These behaviors suggest that a crack will initiate when a critical combination of hydrogen concentration and triaxial stress state is attained. In agreement with this concept, cracks initiated well below the surface of mild notches. An incubation period for crack initiation was observed, which lengthened with decreasing hydrogen concentration and was independent of the applied stress. Strain-induced trapping of hydrogen was proposed to explain this insensitivity to applied stress. The existence of long incubation periods explains why the stress-rupture test is the most sensitive test for hydrogen embrittlement. The incubation period was interpreted as the time required for a critical amount of hydrogen to diffuse to the point of crack initiation. This diffusion process is induced by the severe triaxial stress state, and exhibits the expected reversibility with respect to the applied stress.

The fracture stress was constant over a wide range of hydrogen concentrations and applied stresses, this suggests that crack propagation must await an increase in hydrogen concentration at the crack front. The rate at which the critical hydrogen concentration is attained by diffusion to the crack tip thus determines the crack propagation rate. Crack propagation is viewed as a discontinuous process. In each unit of propagation a crack grows through the region of enhanced hydrogen concentration in advance of the pre-existing crack. Further crack growth must await diffusion of hydrogen to the new region of severe triaxial stress state.

Fracture of Zinc-Monocrystals and Bicrystals: J. J. Gilman, General Electric Co.

Tests of zinc monocrystals have shown that the fracture stress of zinc is reduced by as much as 100X by small amounts of prior plastic glide. Tests of zinc bicrystals have shown that the effect of a grain boundary on fracture depends markedly on the type of boundary. Symmetric boundaries have no effect on either plasticity or fracture. Anti-symmetric boundaries raise the plastic resistance but do not reduce the fracture stress. Asymmetric boundaries cause marked embrittlement. It is shown that fracture begins along the glide plane of a group of blocked dislocations, not ahead of the group and not below it. This is consistent with the behavior of bubble rafts. A simple, approximate theoretical treatment is given that is qualitatively and semi-quantitatively consistent with the experimental results.

Temperature Dependence of Flow and Fracture in Coated Zinc Single Crystals: L. C. Weiner, Columbia University.

A study of the temperature dependence of flow and fracture in tension of clean and copper-coated zinc single crystals, oriented $\chi_{01} = 3°$ and $\chi_{01} = 83°$ has been carried out at temperatures between −196° and 100° C. With crystals, $\chi_{01} = 3°$, a surface film raises both the cleavage and yield strength, the increase in the former being greater than in the latter. In addition, two ductile to brittle transition temperatures have been observed; one at between 60° and 70° C, associated with the onset of large amounts of slip after the completion of a maximum amount of twinning, and the other, at about −80° C, the intersection of the flow and fracture curves, associated with the onset of twinning. A surface film has no effect on the higher transition temperature while it lowers the other approximately 20 degrees.

For crystals oriented $\chi_{01} = 83°$, a surface film decreases the cleavage strength as well as makes it independent of temperature. Further, only one transition temperature exists, defined by the intersection of the flow and fracture curves, and it is associated with the onset of slip. This transition temperature is raised from 50° to 70° C by a surface coating. These observations and effects are described on the basis of a dislocation-pile-up-at-a-barrier model that had been previously used, for crystals $\chi_{01} = 3°$, twins and more specifically, the resolved mean maximum distance between twins and the relationship of this distance with cleavage strength, play a vital role.

Pyramidal Slip in Magnesium: R. E. Reed-Hill and W. D. Robertson, Yale University.

In the course of a study of plastic deformation and fracture of magnesium crystals strained with the tensile axis nearly parallel to the basal plane, experimental evidence showed that $\{10\bar{1}1\}\langle\bar{1}\bar{1}20\rangle$ is an active system at 25° C in a particular orientation, and that slip on $\{11\bar{2}2\}$ planes, which do not contain the close-packed direction, can occur in magnesium. $\{11\bar{2}2\}$ slip bands were identified on specimens oriented with the tensile axis 2° from a $\langle 10\bar{1}0\rangle$ direction and strained to fracture at −190° C, but not on similar specimens tested at 25° C, 150° C, and 286° C. The asterism found in a Laue back-reflection photograph and microscopic observation of slip lines indicate that the slip direction is probably $\langle 10\bar{1}0\rangle$.

Large, discrete $\{10\bar{1}1\}$ pyramidal slip bands have been observed on specimens strained in tension at 25° C with the tensile axis in the basal plane and approximately 17° from a $\langle 10\bar{1}0\rangle$ direction. In all cases, $\{10\bar{1}1\}$ slip bands formed on planes of high orientation factor computed in terms of the external applied stress. The high loads to fracture, the limited ductility at 25° C, and the apparent rarity of $\{10\bar{1}1\}$ slip bands all point to the fact that pyramidal slip is not an important mode of plastic deformation at room temperature.

Grain Boundary Shear in Aluminum: F. Weinberg, Department of Mines and Technical Surveys, Ottawa, Ontario.

Observations have been made of the behavior of grain boundaries under a constant shear stress using controlled orientation tricrystal specimens of aluminum. It was observed that under the proper test conditions grain boundary shear took place with no discernible deformation of the component crystals except in the boundary region. Alternate boundary shear and migration were observed in the boundary region as well as a fine slip structure and appreciable lattice distortions. Measurements of the boundary shear as a function of time were made during the tests and the effects of stress, temperature, boundary angle, and added impurities on the shear – time curves were determined. Considerable scatter was obtained in repeat tests so that an average shear – time curve was determined for a given set of test conditions. Attempts were made to determine an unambiguous activation energy value for the boundary shear process but it was found that the observations could not be described by a single activation energy.

It was observed that there was a marked increase in stress required to produce a given shear in a given time at temperatures below approximately 425° C. The size of the boundary angle appeared to influence the boundary shear behavior in the following way. For small tilt or twist type boundaries (less than 3°) no shear was observed; with angles larger than approximately 15° the shear was relatively insensitive to the boundary angle; between the two limits there was a gradual transition in the shear behavior. Adding small amounts of either copper (up to 0.2%) or iron (0.03%) to the super pure aluminum had no appreciable effect on the boundary shear. Larger additions of iron (0.1%) prevented boundary shear from taking place.

Delay Time in Face-Centered Cubic Metals: I. R. Kramer and H. R. Peiffer, Rias, Inc.

Previous investigations have shown that there is a time delay for the initiation of plastic flow in body-centered cubic and hexagonal close-packed metals. A delay time was not found in face-centered cubic metals. In this investigation, single crystals of high-purity copper and aluminum were compressed at room temperature and in liquid nitrogen prior to the delay time measurement. The measurements were made at −195° C. A delay time of the order of 10^{-4} – 10^{-3} seconds was found in crystals of several orientations in regions where cross-slips may be expected. It is not clear whether a delay time exists for those specimens where easy glide may be expected. Studies of the slip line traces show both cross-slip and conjugate slip planes are active.

The delay time phenomenon differs from that found in body-centered and hexagonal metals in that it is only present when the

specimen has been plastically deformed prior to testing. Therefore, it is unlikely that it is associated with impurity-dislocation locking, but rather with a dislocation-dislocation type interaction. Vacancy-dislocation interaction is also an improbable cause because of the fact that the delay time can be introduced by deformation at low temperatures (−195° C), where vacancy migration is extremely slow. The phenomenon may possibly be associated with the formation of stacking faults or sessile dislocations.

Work Hardening on the Latent Slip Directions of Alpha-Brass During Easy Glide: W. L. Phillips and W. D. Robertson, Yale University.

Stress-strain curves were obtained for single crystals of alpha-brass of different orientations at room temperature in simple shear on {111} planes and in <110> directions. Specimens were strained various amounts in a given slip direction, unloaded, and immediately strained in a second slip direction 60°, 120°, or 180° from the original slip direction. Crystals extended in tension and direct shear had comparable critical resolved shear stresses and stress-strain curves. The density of slip lines in direct shear and in tension, was essentially the same. Three types of cross-slip were found: intimate, prominent, and peculiar.

The stress-strain curves obtained in shear were independent of initial orientation, choice of {111} slip plane, choice of <110> slip direction, prior annealing temperature, and rate of cooling after annealing. There was no recovery after annealing for four hours at room temperature or 200° C; recovery was observed after four hours at 400° C. The crystals showed no asterism and mechanical properties were completely recoverable up to 20 pct. It was found that there is a barrier to slip in all latent close-packed directions, and that the magnitude of these barriers, evaluated at 2 pct strain, is proportional to prior strain and independent of the choice of latent direction in the {111} plane. The formation of Cottrell-Lomer barriers is discussed as a possible explanation for the hardening of the latent systems.

Impurity Substructures in Zinc Single Crystals: H. G. F. Wilsdorf, Franklin Institute.

Single crystals of zinc, 30 cm long and 1 cm in diameter, were grown at various speeds in a vertical furnace according to the Bridgman method. Three types of specimen containing less than 0.03, 0.001, and 0.0001 pct impurities respectively have been investigated, and sections of the crystals parallel and perpendicular to the axis of growth at various positions were examined metallographically. While no substructure was detected in crystals with a purity of 99.999 pct or better, specimens of 99.97 zinc showed three types of substructure: lineage structure, cell structure, and lamellar structure. A pronounced orientation dependence of the lineage structure pattern with respect to the axis of growth was found and also a uniform variation in block size over the length of the crystal. Following the theory of Teghtsoonian and Chalmers and of Frank, the boundaries of the lineage structure are interpreted as the result of vacancies condensing into sheets, thereby forming concentric dislocation loops. The dislocation density in the boundaries of the lineage structure was determined. Results with regard to the cell structure and the lamellar structure will be discussed, and it appears that these substructures develop completely independent of the lineage structure.

Oxidation of Zircaloy-2 and -3A at 300 Deg. C to 850 Deg. C: E. A. Gulbransen and K. F. Andrew, Westinghouse Electric Corp.

The oxidation of Zircaloy-2 and -3A was studied over the temperature range of 300° C to 850° C. From 500° C to 750° C the alloys oxidized at a faster rate than pure zirconium, while below 500° C the pure metal reacted at a faster rate. An analysis of the measurements show that the cubic rate law fits the data best for the abraded specimens. However, if an initial deviation is disregarded, the parabolic rate law can be fitted to the data. The rate data for chemically polished specimens show a good fit to the parabolic rate law. When the logarithms of the parabolic rate law constants were plotted against 1/T, a heat of activation of 28,600

calories per mole was calculated. Using the classical theory of oxidation and diffusion the rate data suggest a reaction mechanism based on the diffusion of zirconium ions by means of cation vacancies.

The transition phenomenon in the rate of oxidation was confirmed and further studied as a function of temperature for the two alloys. The weight gains for transition increased as the reaction temperature was raised. This fact results in the phenomenon that the times for transition reach a minimum near 750° C and then increases. A comparison of these results with those of other workers suggest that the transition phenomenon in air, oxygen, and steam atmospheres has a common origin. An analysis was made of the rates of oxidation, the color and properties of the oxide film and the thickness of the oxide for transition. The analysis suggests that transition in the initial kinetics to the final kinetics was associated with a failure in the adherence of the oxide film on the alloy.

Structural Aspects of the Corrosion of Stainless Steel at 500 Deg. to 700 Deg. C in Gaseous Atmospheres: E. A. Gulbransen, T. Copan, and D. van Rooyen, Westinghouse Electric Corp.

Electron optical studies were made on the corrosion products formed on 304 stainless steel in (1) dry air and oxygen, (2) oxygen saturated at 25° C with H_2O vapor, (3) oxygen saturated at 25° C with H_2O vapor plus a few parts per million of HCl vapor. In addition to the formation of the normal oxide film many fine whiskers were formed at 600° C in wet and dry oxygen atmospheres. These whiskers grew roughly perpendicular to the surface and were 100 to 500 Å thick and up to 50,000 Å in length. Some areas of the specimen are free from whiskers while other areas contain up to 10^8 whiskers per cm^2.

In atmospheres containing HCl vapor at 600° C a striking new crystal habit was noted. In addition to whiskers, fan-shaped single crystals of Cr_2O_3 were formed growing roughly perpendicular to the surface and having dimensions of the order of 100 to 200 Å in thickness, 10,000 to 50,000 Å in height and up to 100,000 Å long. These crystals often appear in parallel layers with a spacing of the order of 1 micron. Prestressing of the stainless steel specimens greatly accelerates the growth of the fan shaped crystals. The possible role of this type of crystal growth in stress corrosion cracking was discussed.

Fabrication of Uranium Dioxide Fuel Element Shapes by Hydrostatic Pressing: H. W. Newkirk, Jr., and R. J. Anicetti, General Electric Co.

Mallinckrodt "ceramic grade" uranium dioxide, having a surface area of 1.0 M^2/gm, an average particle diameter of 1.95 microns and a packed density of 2.66 gm/cc, was hydrostatically pressed in special molds at 40,000 psi. The tubes, 3.163 in. O.D. × 2.519 in. I.D. × 13.00 in. long, 2.813 in. O.D. × 0.625 in. I.D. × 12.00 in. long and 1.880 in. O.D. × 1.260 in. I.D. × 14.00 in. long; the rod, 1.075 in. in diameter × 12.16 in. long; and the spheres, 3.240 in. and 2.20 in. in diameter, respectively, had green densities of 58 pct of the theoretical density. Compaction ratios were were calculated to be 1.8 to 1.0. The shapes were sintered in a hydrogen atmosphere at 1750°C for eight hours to 92 pct of the theoretical density. In addition, slip cast spheres, 0.50 in. in diameter, extruded rods, 0.50 in. in diameter × 6.00 in. long, and cold-pressed rings, 3.660 in. O.D. × 2.620 in. I.D. × 1.50 in. in height, were repressed hydrostatically at 40,000 psi. Repressing resulted in a minimization of density gradients, healing of pressure cracks, 1-4 pct. reduction in firing shrinkage, 7-10 pct. increase in green density and a 2-6 pct. increase in sintered density. Techniques were developed for hydrostatically cladding uranium dioxide fuel element shapes such as spheres. Lead tubes and rods for mock-up assemblies, having the same dimensions as the uranium dioxide shapes discussed above, were fabricated by hydrostatically pressing lead powder in special molds at 15,000 psi. The techniques and equipment employed are discussed in detail.

MONDAY, NOVEMBER 4

4:30 pm, Parlor B

IMD MEMBERSHIP COMMITTEE MEETING
J. H. Keeler, Chairman

6:00 pm, Parlor C

METALLURGICAL SOCIETY EDUCATION COMMITTEE DINNER MEETING
R. Schuhmann, Jr., Chairman

TUESDAY, NOVEMBER 5

7:30 am, Parlor B

BREAKFAST FOR TUESDAY SESSION CHAIRMEN AND AUTHORS

8:00 am to 4:00 pm, First Floor Foyer

REGISTRATION

9:00 am to 12:00 m, Grand Ballroom

SYMPOSIUM ON TITANIUM
L. S. Busch, Mallory-Sharon Titanium Corp.

Introductory Remarks: L. S. Busch, Mallory-Sharon Titanium Corp.

Keynote Speaker: John H. Garrett, Executive Secretary, Coordinating Committee on Materials, Office of Assistant Secretary of Defense.

TITANIUM'S PROGRESS, AT HOME AND ABROAD

United States Progress in Titanium—1956-1957: W. J. Harris, Jr., Minerals and Metals Advisory Board of National Academy of Science, National Research Council.

Question and answer period from audience.

European Progress in Titanium: Eric Swainson, Imperial Chemicals Industries, Birmingham, England.

Question and answer period from audience.

9:00 am to 12:00 m, Cotillion Room

SEMINAR ON SCIENCE OF METAL HARDENING
M. E. Fine and J. Washburn, Chairmen

TUESDAY, NOVEMBER 5

Effect of Alloying on the High-Temperature Creep Properties of Metals: J. Weertman, United States Naval Research Laboratory.

At high temperatures the steady-state creep of metals is described by the following equation which is valid for stresses up to 1000–10,000 psi:

$$\text{creep rate} = C\sigma^n \exp(-Q/kT)$$

where σ is the stress, Q is an activation energy, kT has its usual meaning, and n and C are constants. For pure metals the value of n is about 4.5. By alloying the value of n can be reduced to values in the range of 3.0 to 3.5. If dislocation climb is the rate-controlling creep process the values of C and Q will change upon alloying but the value of n ought to remain constant. Since n can be reduced by alloying it appears that processes other than dislocation climb can control the creep rate of alloys. It can be shown that a dislocation climb model which predicts that n = 4.5 when climb is rate controlling will also predict that n = 3.0 if any microcreep mechanism controls the rate of motion of the dislocations. For a typical substitutional alloy it appears that climb will control the creep rate for alloy contents up to 1 atomic pct., that Cottrell-Jaswon or Suzuki microcreep may control the creep for alloy contents in the range 1 to 10 pct., and that Schoeck microcreep or the microcreep mechanism inherent in Fisher's short-range-order hardening theory may control the creep at high-alloy contents. However, if the diffusion constant of the alloying element is many orders of magnitude larger than that of the host element, dislocation climb may be the rate controlling process up to high alloy contents.

Magnetic Study of Precipitation Hardening: J. D. Livingston, General Electric Co.

For the evaluation of various theories of precipitation hardening a correlation of mechanical properties with such parameters as the size and spacing of the precipitate particles would be extremely useful. Such data are difficult to obtain for most alloys because the particles are submicroscopic in size in the range of optimum hardness. Where the precipitate is ferromagnetic, however, magnetic measurements can be used to determine the various parameters describing the particle dispersion.

Hardness and tensile measurements have been made on a copper-2 pct. cobalt alloy in the early stages of aging, in conjunction with magnetic measurements which give the total volume of precipitate and the average particle volume. After the first few minutes at 600° C, the total volume of precipitate remains nearly constant. The various mechanical properties each go through a maximum as the particles grow. It is particularly interesting that the hardness and yield stress continue to increase markedly after the cobalt has essentially all precipitated, and as the particle size, and hence the interparticle spacing, increases.

The effects of deformation on the magnetic properties have also been studied. Deformation by tension or compression induces a uniaxial magnetic anisotropy. The temperature independence of this anisotropy, plus its insensitivity to subsequent recrystallization, suggests that it is due to the change in shape of the ferromagnetic precipitate particles during deformation. A model based on homogeneous deformation gives good quantitative agreement with observed data up to 30 pct. compressive strain. It is believed that magnetic measurements in such an alloy can be useful in examining the internal deformation processes, on a scale as small as the precipitate particles themselves.

Strength of Age-Hardened Alloys: A. Kelly, Northwestern University.

The crystallographic structures produced during the aging of a supersaturated solid solution are, in general, varied and complex. For this reason a variety of processes may contribute to the strength of an age-hardened alloy and it is unlikely that a single theory will account for the strength at all stages of aging.

The present review considers in detail the aluminum-copper and aluminum-silver systems, since these have been most thoroughly studied using X-ray methods. The appearance of the various structures correlates very well with the various hardening stages. Stress-strain curves of single crystals of Al-Cu, aged by various

amounts, are presented and the appearance of the slip lines discussed. A broad correlation is found between the slip line appearance and the type of stress-strain curve.

An attempt is made to account for the strength of age-hardened alloys at various stages of the aging sequence in terms of current theories. It is concluded that the overaged condition is the one best understood at present. Measurements of the temperature dependence of the flow stress seem to offer the simplest means of testing the various theories.

An explanation of the strength of Al-Cu and Al-Ag alloys in the cold-hardening stage is put forward which associates the flow stress with the work done in shearing the Guinier-Preston zones. Estimates of this may be made from the heats of reversion. The calculated flow stresses are in reasonable agreement with measured values.

Inhomogeneous Deformation in the Austenite-Martensite Transformation: D. S. Lieberman, University of Illinois.

The total transformation distortion in the austenite-martensite transition can be considered to consist of two parts: the pure Bain distortion which brings about the *per se* change in crystal structure, and the inhomogeneous distortion which is such that a plane free from stress on a microscopic scale exists between the parent and product phases. This plane of zero average distortion is identified with the habit plane. The pattern of inhomogeneity, plane and direction of slip and/or twinning in the parent and/or product phase is of great importance since it is intimately related to the dislocation arrays which are taking part in the nucleation and growth processes and other phenomena.

Since this pattern has not been observed except in a very few systems, the several recent theories that require its specification to predict the crystallographic features of the transformation must assume a pattern of inhomogeneity in the many cases where this information is not known. In the past, considerable effort was spent examining several assumed slip systems and comparing each set of predicted features with observations. Clearly this is not the most expeditious way of determining which pattern of inhomogeneity corresponds to reality.

The purpose of this presentation is to show how this pattern can be obtained directly from observations. The essence of the method consists of working the problem previously done in reverse: given a particular set of observations of the lattice parameters of the initial and final structures, interface plane normal, orientation relationships, and magnitude and direction of shear, to determine uniquely that pattern of inhomogeneity which could produce that particular set of crystallographic features. The technique involves a more elegant and considerably shorter version of the recent graphical formulation of the Wechsler-Lieberman-Read theory of diffusionless phase changes. Since this improved treatment has not yet been published, it is first described briefly.

The "inverse" method is then applied to the determination of the pattern of inhomogeneity in one of the few cases where accurate experimental data is available on a single transformation process: the f.c.c. to b.c.t. austenite-martensite transformation in an Fe-Ni-C alloy. The predicted pattern of inhomogeneity is discussed and compared with available experimental information. Possible limitations as well as advantages of the method are discussed.

9:00 am to 12:00 m, Embassy Room

NON-FERROUS AND HIGH-TEMPERATURE ALLOYS

R. W. Guard and H. Burte, Chairmen

Sand Cast Magnesium-Rare Earth Metal-Zirconium Alloys: T. E. Leontis, The Dow Chemical Co., and D. H. Feisel, Carnegie Institute of Technology. (JOURNAL OF METALS, October 1957)

Addition of zirconium to cast magnesium-rare earth metal alloys results in a marked degree of grain refinement and a significant improvement in strength and ductility at temperatures up to 400° F. The strength properties and creep resistance of Mg-didymium-Zr alloys are markedly superior to those of Mg-Mischmetal-Zr alloys. Results of studies on alloys containing various proportions of Mischmetal and didymium, and didymium and cerium and didymium are also presented. In general, both in cerium/didymium and Mischmetal/didymium alloys, the strength properties increase with increasing didymium content.

Blister Formation in Rolled Aluminum: J. H. O'Dette, Aluminum Laboratories, Ltd. (JOURNAL OF METALS, July 1957)

Blister raising discontinuities have been located in sheet ingots and followed by means of nondestructive testing methods through the various stages of sheet production to the formation of blisters. The relative importance of gas content and ingot discontinuities has been determined. The use of a fabricating technique based on at least 40 pct. cold reduction of the as-cast ingot prior to the application of normal hot and cold rolling procedures has been shown to eliminate blisters. An explanation for this is offered.

On the Release of Hydrogen from Molten Aluminum: Asutosh Pal, M/s Aunapurna Metals Works, Calcutta, and H. M. Davis, Pennsylvania State University.

Elastic Properties of Yttrium and Eleven of the Rare Earth Elements: J. F. Smith, C. F. Carlson, and F. H. Spedding, Iowa State College. (JOURNAL OF METALS, October 1957)

Elastic constants of polycrystalline samples of yttrium and eleven of the rare earths have been measured. Linear trends with atomic number were observed in both compressibility and shear modulus. Deviations from these trends are apparently related to crystal structure.

Gas Desorption of Copper Powders: J. C. Tobin, General Electric Co., and M. J. Sinnott, University of Michigan.

A technique for collecting and analyzing the small quantities of gases desorbed on heating metal powders has been developed. The gases collected from copper powders of various types of manufacture have been analyzed and found to contain H_2O, CO_2, and SO_2. The quantities of gas evolved varies from 0.05 to 1.0 milliliters, under standard conditions of temperature and pressure, per gram of powder. The source of the gas has been traced to surface films on the powder.

Copper-Silica and Copper-Alumina Alloys of High-Temperature Interest: K. M. Zwilsky and N. J. Grant, Massachusetts Institute of Technology. (JOURNAL OF METALS, October 1957)

Utilizing relatively coarse copper powders and several sizes of silica and alumina powders, alloys containing up to 10 volume pct of oxide were made. The alloys were prepared by mechanical mixing of powders, followed by cold hydrostatic pressing, sintering, and hot extrusion. Measurements were made of room temperature tensile properties, recrystallization temperature, creep rupture properties from 250 to 450° C, and resistivity. In addition metallographic studies were made of the resultant structures. Of particular interest was the stability of the structure with respect to temperature, time, and stress.

TUESDAY, NOVEMBER 5

Metallurgical Observations of Nitrides in Chromium: I. S. Servi and W. D. Forgeng, Electro Metallurgical Co., Div. of Union Carbide Corp.

Whereas considerable attention has been given to the formation of chromium nitrides in steel, the literature does not offer much information on the presence of nitrides in chromium metal. The first preparation of Cr_2N by reaction of chromium with nitrogen at elevated temperatures was reported by Briegleb and Geuther. Earlier work dealt with the synthesis of the same compound from chromium salts and ammonia. Fersw first reported the existence of another compound, CrN, which was found to be distinguishable from Cr_2N, based on relative reactivities in sulfuric acid. Cr_2N was transformed into CrN by heating the former in nitrogen. Kinetic studies of the chromium-nitrogen reaction were made by Neumann et al. The crystallographic structures of the two compounds were determined by Blix, physical and chemical properties were given by Juza and Ohnon et al, microhardness data by Korobov and thermodynamic data by Sano, Sato, and Morgovoi and Samarin.

Determination of Orientation in Magnesium by Polarized Light: C. W. Pearsall and S. J. Couling, Dow Chemical Co. (JOURNAL OF METALS, July 1957)

9:00 am to 12:00 m, Exhibit Hall

SESSION I—RECENT DEVELOPMENTS IN STEELMAKING PRACTICES

(See listing of Iron and Steel Division sessions on page 63 of program.)

12:00 m, Pent House, 42nd Floor

IMD EXECUTIVE COMMITTEE LUNCHEON MEETING
W. R. Hibbard, Jr., Chairman

2:00 to 5:00 pm, Grand Ballroom

SYMPOSIUM ON TITANIUM

Introductory Remarks: L. S. Busch, Mallory-Sharon Titanium Corp.

Panel and Discussion Moderator: N. E. Promisel, Bureau of Aeronautics, Department of Navy.

OPINIONS AND IDEAS ON THE MANUFACTURE AND USE OF TITANIUM

Panel Members:

R. S. Reinhold, Boeing Airplane Co.
A. Hurlich, Convair, Div. General Dynamics Co.
W. H. Sharp, Pratt and Whitney Aircraft, Div. United Aircraft Corp.
G. J. Wile, General Electric Co.
C. B. Voldrich, Battelle Memorial Institute
Robert T. Jameson, United States Air Force
Stuart Arnold, Ordnance Materials Research Office
W. E. Lusby, E. I. du Pont de Nemours and Co., Inc.
W. W. Minkler, Titanium Metals Corp. of America
L. S. Busch, Mallory-Sharon Titanium Corp.
T. F. Perry, Republic Steel Corp.
W. L. Finlay, Rem-Cru Titanium, Inc.

Question and answer period from audience.

TUESDAY, NOVEMBER 5

2:00 to 5:00 pm, Cotillion Room

RESEARCH SUMMARIES ON SCIENCE OF METAL HARDENING
R. S. Davis and H. W. Paxton, Chairmen

Solute Strengthening in 80 Ni-20 Cr Alloys: R. W. Guard, General Electric Co.

The effects of five different solute solutions (Cr, Mo, Va, Ti, Al) on the plastic properties of an 80 Ni-20 Cr base has been determined. The effects of solute additions on yield stress and strain hardening as well as the lattice parameter have been studied. By correlating various parameters of yielding and flow with the atomic characteristics of the solute, the following conclusions have been reached:

1. The yield stress and rate of strain hardening are both increased by solute additions. This increase is linear with concentration for dilute solutions.

2. There is another effect related to the chemical nature of the solute. Elements farther from Ni in the periodic table harden to a greater extent for the same change in lattice parameter. This effect is similar to the valency effect noted for other systems not involving transition metal elements.

3. In solutions near the limit of solubility the solute strengthening is less than predicted by the linear trend in dilute solutions.

The general conclusion is reached that the behavior in multicomponent systems follows the principle established for simple binary systems.

Substitutional Solution Hardening in Copper Alloys: Carl Wiseman, University of California.

The object of this investigation was to determine the cause of substitutional solid solution strengthening. Shear tests were conducted on single crystals of high-purity copper and of copper-manganese and copper-aluminum alloys. Each specimen was tested at room temperature after anneals at various temperatures. The specimens were next deformed in a manner that introduced substructure and then tested again after various anneals. An attempt was made to interpret the results in terms of current theories of solution strengthening. It was concluded that solution strengthening was due to the interaction of solute atoms with the substructure in the metallic lattice. Solution strengthening was found to be structure sensitive and hence it was not possible to find a simple law defining this phenomenon.

Quench Hardening in Pure Gold: J. W. Kauffman and M. Meshii, Northwestern University.

The effect of rapid quenching from temperatures in the range of 500° C to 1040° C on the mechanical properties of 99.999 pct gold wires was studied. The specimens were deformed in tension at various temperatures from liquid nitrogen to 200° C. Upon aging at temperatures from 25° C to 100° C subsequent to quenching, the yield stress was found to increase markedly, the magnitude depending on the quenching temperatures and for slower quenches on the rate of quenching. Increases in the rate of work hardening in the early stages of deformation were also observed with aging.

The activation energy corresponding to the rates of increase in yield stress is 0.7ev. This is interpreted in terms of the energy of motion of quenched-in defects. Changing the testing temperature over the range −196° C to 100° C had no effect on the increase in yield stress resulting from quenching and aging within the experimental sensitivity. Therefore, hardening by a Cottrell atmosphere or pining of dislocations by point defects is not considered to be the primary mechanism involved here. Rates of recovering subsequent to quench hardening were determined in the range 500° C to 850° C. Preliminary data gives an activation energy in agreement with that for self diffusion.

The effect of quenching temperature can be divided into three temperature ranges. Range I lies from about 930° C to the melting temperature, range II from 930° C to 740° C, and range III below 740° C. Little temperature dependence is found much above 930° C, indicating the quench is not sufficiently rapid, some of the dislocation

recovering during the quench. In range II the increase in yield stress is approximately proportional to the amount of quenched-in defects. Range III exhibits a very rapid fall off with decreasing temperature to no quench hardening effect. A mechanism involving disorder produced as a result of coagulation of vacancies will be proposed.

Grain Boundary Sliding in Copper Bi-Crystals: J. Intrater and E. S. Machlin, Columbia University.

The phenomenon of grain boundary sliding (motion of grains along a common boundary) was studied in bi-crystals of copper which were oriented to minimize slip in the adjoining grains. It was found that sliding occurred within a very narrow zone. Prior plastic deformation is not necessary to achieve boundary sliding; however, when specimens were plastically deformed prior to grain boundary sliding, a decrease in the flow resistance of the region adjoining the grain boundary to shear stress parallel to the boundary was observed. Sliding is spasmodic with no incubation time and occurs with an activation energy of 46,000 cal/mol when tested in a vacuum of 5×10^{-4} mm Hg and 29,000 cal/mol when tested in hydrogen. Cracks along the boundary are found on bi-crystals tested in vacuum and isolated voids are found on testing in hydrogen. The number of voids is directly dependent upon the amount of grain boundary sliding and is independent of temperature.

It is believed that during grain boundary sliding pure sliding occurs along the straight sections of the boundary between the boundary projections (jogs). High stresses are developed at these jogs, inducing local plastic deformation. After sufficient plastic deformation fracture occurs, producing voids.

Effect of Carbide Dispersion on the Strength of Tempered Martensite: A. M. Turkalo and J. R. Low, Jr., General Electric Co.

The carbide dispersions in three essentially plain carbon martensitic steels (0.42 pct, 0.56 pct, 0.75 pct C) have been studied after varying tempering treatments (400 – 1250° F). The purpose of the study was to verify existing quantitative data on the relationship between carbide spacing and tensile properties and to extend this earlier data to finer structures by the use of electron microscopy. In contrast to the earlier data, a linear relationship between the logarithm of the mean interparticle spacing (mean free ferrite path) and the yield strength does not hold for the entire range of tempered martensite structures. However, linearity is obtained throughout this range of structures if one considers the ferrite grain boundaries in the measurement of the mean free path in the structures containing the very coarse dispersions (highly tempered) where the carbides occur almost entirely as large spheroids scattered at grain boundaries.

The method of calculating ferrite grain size in tempered martensites from the carbide particle diameters, as proposed by several investigators, was found to be valid only for the very coarsest carbide dispersions and not over the full range of tempering temperatures examined.

Dispersion Hardening by Spherical Particles: H. R. Peiffer and R. H. Read, Rias, Inc., and A. J. Shaler, Pennsylvania State University.

The distribution of stresses about spherical hard particles embedded in a non-coherent metallic matrix is calculated for unilateral applied stress. The calculation is made analytically for a single disc-like hard particle in a softer two-dimensional matrix, then by means of rubber analogs it is extended to various arrays of disc-like particles in a two-dimensional matrix and to non-disc-like particles. Thermal stress patterns in arrays are considered. Finally, the strengths of three-dimensional arrays are investigated experimentally in specimens made of steel spheres or cubes embedded in silver and silver solder. The results are applicable to the design of dispersion-hardened systems such as two-phase alloys made by powder-metallurgy or by the SAP process, and to the study of dispersed systems like pearlite and spheroidite.

The basic calculation, for a single disc in a two-dimensional matrix under unilateral tension, is made by the "displacement

function" technique of Donnell and of Edwards. It shows that the most important variables affecting the stress distribution are the shape of the particle and the ratio of the elastic moduli of the two phases. The investigation, outlined above, shows that the results of the calculation apply, with appropriate modification, to more general three-dimensional systems of particles. With proper choices of particle shape, array size, and separation, and a proper choice of moduli, the greatest stress concentration at any point within the material can be made as low as 1.3, and the strength can be made to approach that of the harder phase.

Detection of Dislocation Tilts and Strains by X-Rays: Larry Kaufman and S. A. Kulin, Lincoln Laboratory, Massachusetts Institute of Technology.

The X-Ray Double Crystal Spectrometer has been utilized to study the perfection of single crystals of copper grown by both the Bridgman and Czochralski methods. The rocking curve halfwidth β has been measured for the [111] and [222] reflections using monochromatic CuK_{α_1} and MoK_{α_1} radiation. The results of the measurements on each crystal may be described by a straight line of the form:

$$\beta = H(1 - \frac{S}{I}\tan\theta) \qquad (1)$$

where θ is the Bragg angle, S is the slope, and I is the intercept.

Theoretical calculations of the effect of a Cauchy distribution of reciprocal dislocation spacings in a crystal on the value of β measured at a given value of θ yield Eq. (2)

$$\beta = \frac{2}{\nu}(1 + 0.8\tan\theta) \qquad (2)$$

where ν is the Cauchy distribution coefficient.

Experimental values of (S/I) ranging from 0.2 to 1.0 have been determined and are in fair agreement with theory. The dislocation density N_D of the copper crystals used in these experiments may be estimated by using the Gay, Hirsch and Kelly formula.

$$N_D = \frac{\beta^2}{9b^2} \qquad (3)$$

(where b is the Burgers vector). Equation (3) does not take into account the contribution of dislocation strain to the rocking curve. Using values of N_D between 5×10^7 cm^{-2} and 8×10^8 cm^{-2} were

$$N_D = \frac{I^2}{9b^2} \qquad (4)$$

obtained.

It should be noted that simultaneous application of Eqs. (2) and (3) implies a cross relationship between the number of dislocations present and their distribution in the crystal.

Effect of Order-Disorder on the Strength of Beta Brass: Norman Brown, University of Pennsylvania.

The effect of order on the mechanical strength may be viewed from two aspects (1) the size of the anti-phase domains and (2) the degree of order. Cottrell predicted that maximum strengthening occurs for an intermediate domain size. Data by Broom and Biggs on $AuCu_3$, and apparently data by Brown and Green on beta brass, substantiated the theory. New data on beta brass appears to contradict the Cottrell theory. The additional data consist in varying the quenching rate by varying the quenching medium or the specimen size. The new data show that the previously observed maximum strength produced by a water quench from 445° C is shifted to quenching lower temperatures as the quenching rate was decreased and that the curve of yield point versus quenching temperatures reaches a plateau beginning at Tc when the quenching rate was greatest. The above results are interpreted to mean that the maximum strength is associated with the quenching-in of a maximum number of imperfections and/or disorder and not with the quenching-in of a critical domain size. Electrical resistivity measurements support this viewpoint.

The second aspect of the work consists in determining the yield

point of beta brass as a function of temperature. With decreasing temperature the yield point shows a sudden two-fold increase in the neighborhood of T_c and reaches its maximum value at 200° C. Part of the sharp increase near T_c is associated with short-range order. A simple theory shows that the strengthening in the region of long-range order is less than that predicted for a unit dislocation moving alone and much greater than that expected from the movement of a super dislocation having the equilibrium spacing. The maximum in yield point observed at 200° C is explained by the change in coherence of the super dislocation. The variation of elastic modulus with temperature is not sufficient to account for this maximum.

2:00 to 5:00 pm, Embassy Room

NUCLEAR METALS
R. Van Thyne and D. W. Lillie, Chairmen

Effect of Heat Treatment on the Hardness and Microstructure of Uranium-Titanium Alloys: D. L. Douglass and L. L. Marsh, Jr., Battelle Memorial Institute. (JOURNAL OF METALS, October 1957)

A correlation between the heat treatment and hardness of three uranium-titanium alloys ranging in composition from 8.5 to 50 a/o titanium was conducted. From this study the following important observations were made:

(1) A direct quench of gamma uranium-titanium solid solution resulted in the formation of hard martensitic phase in low-titanium alloys.

(2) Subsequent tempering increased the hardness further by the rejection of a fine dispersion of U_2Ti.

(3) Similar hardness levels were obtained by isothermal transformation of an 8.5 a/o titanium alloy at 400 and 500° C.

(4) The crystal structure of the phases present at the solution-treating temperature, and the effect of temperature within a given equilibrium phase field, affected the hardness of both quenched and isothermally transformed alloys.

Preferred Orientation in Rolled Uranium Rods: M. H. Mueller and H. W. Knott, Argonne National Laboratory, W. P. Chernock, Combustion Engineering, Inc., and P. A. Beck, University of Illinois.

A study has been made of the preferred orientation in uranium rods rolled to various reductions at 300° C and 600° C. The rods used for the 300° C final rolling were obtained from three groups which had been previously either rolled at 600° C, or rolled at 300° C and annealed at 550° C, or beta treated. The rods used for the 600° C final rolling were obtained from material previously beta-treated. It was found that, regardless of the starting material, the orientation obtained was the same if the reduction at 300° C was approximately 70 pct or greater. A considerable variation in orientation was observed in rods with lower reduction. The type of orientation developed by 600° C rolling is somewhat different from that obtained by 300° C rolling. The recrystallization texture in rods rolled at 300° C may be described as consisting of {010} and approximately {140} fiber texture components. Thermal cycling and thermal expansion data are also given for these rods.

Transformation Kinetics of Uranium-Zirconium Alloys Containing 50 and 60 Weight Per Cent Uranium: J. J. Kearns, Westinghouse Electric Corp.

Uranium-Silicon Epsilon Phase: S. Isserow, Nuclear Metals Inc. (JOURNAL OF METALS, October 1957)

Properties of the U-Si phase have been investigated, with emphasis on the means of obtaining material resistant to corrosion in

water. Evidence is presented that the corrosion resistance depends on the absence of phases other than ε and that the desired ε phase has a silicon content in the range of 3.9 to 4.6 wt pct rather than the 3.78 wt pct stoichiometric U_3Si. It was necessary to develop an analytical method to overcome the apparently low silicon content found in this system under certain conditions. Attempts to fabricate this alloy were devoted primarily to coextrusion with Zircaloy-2. Extrusion constants are reported.

Irradiation Stability of Low Weight Per Cent Uranium-Zirconium Alloys: A. H. Willis, General Electric Co.

Metallography of Irradiated Uranium-Preparation, Cathodic Vacuum Etching, and Replication: T. K. Bierlein, J. R. Morgan, and G. R. Mallett, General Electric Co.

Facilities and procedures used in the preparation and metallographic examination of specimens made intensely radioactive by neutron irradiation in atomic reactors are described. The applicability of remote cathodic vacuum etching and remote replication to optical and electron metallography in the study of neutron irradiation damage in uranium is demonstrated.

Corrosion Mechanism of Uranium-Base Alloys in High-Temperature Water: M. W. Burkart and B. Lustman, Westinghouse Electric Corp. (JOURNAL OF METALS, January 1958)

Uranium-base alloys exposed to high temperature water fail either by uniform oxidation or by sudden cracking and disintegration of the metal. The disintegration results from the oxidation of a second phase, which is precipitated during the corrosion process. The precipitate has been identified as a meta-stable hydride of uranium.

A Mechanism by Which Zr and Ti Inhibit Corrosion and Mass Transfer of Steels by Liquid Heavy Metals: O. F. Kammerer, J. R. Weeks, J. Sadofsky, W. E. Miller, and D. H. Gurinsky, Brookhaven National Laboratory. (JOURNAL OF METALS, January 1958)

Zirconium and titanium inhibit solution mass transfer of steels by liquid Bi, Hg, and Pb. It is shown that in Bi and Hg, these absorb on the surface of the steels and subsequently react with nitrogen and possibly carbon from the steels to form inert, adherant layers of ZrN, or TiN, or TiN-TiC. Data are presented that describe the condition under which the deposits form. These inhibitors decrease the rate of solution of iron into bismuth, and require a higher supersaturation for precipitation of iron from bismuth.

2:00 to 5:00 pm, Exhibit Hall

SESSION II—CONTINUOUS STEELMAKING

(See listing of Iron and Steel Division sessions on page 63 of program.)

4:00 pm, Parlor C

NUCLEAR METALLURGY COMMITTEE MEETING
F. G. Foote, Chairman

TUESDAY, NOVEMBER 5

6:30 pm, Embassy Room

COCKTAIL PARTY FOR DINNER GUESTS

7:00 pm, Cotillion Room

ANNUAL FALL DINNER

Toastmaster: W. R. Hibbard, Jr., Chairman, Institute of Metals Division.

Welcome: Michael Tenenbaum, Chairman, Chicago Section, AIME.

Speaker: Professor John A. Wilson, Oriental Institute, University of Chicago.

Topic: "Five Thousand Years of Modern Egypt."

WEDNESDAY, NOVEMBER 6

7:30 am, Parlor B

BREAKFAST FOR WEDNESDAY AND THURSDAY SESSION CHAIRMEN AND AUTHORS

7:30 am, Parlor C

METALLURGICAL SOCIETY PROGRAMS COMMITTEE BREAKFAST MEETING
W. J. Harris, Jr., Chairman

8:00 am to 4:00 pm, First Floor Foyer

REGISTRATION

9:00 am to 12:00 m, Grand Ballroom

SYMPOSIUM ON URANIUM AND URANIUM DIOXIDE
A. R. Kaufmann and J. M. Taub, Chairmen

Development of Casting Techniques for Uranium and Uranium Alloys: G. E. Jaynes, D. T. Doll, and J. M. Taub, Los Alamos Scientific Laboratory.

Micarta tube and double-walled, water-cooled, steel tank furnaces used for the vacuum melting and casting of uranium are described. Vacuum pumping systems and high frequency power generating equipment are discussed. Experiments in which uncoated induction coils were used successfully to melt small heats of metal are described. Information is presented concerning the use of graphite crucibles and molds and the application of refractory coatings to prevent crucible-metal and mold-metal reactions. The casting process covering furnace set-up, pouring temperatures, mold temperatures, out-gassing, post heating, casting recovery, and crucible and mold clean-up is discussed. The casting of uranium alloys using induction stirring of the melt to promote homogeneity in the casting is described. Mention is made of experiments in which castable refractories, glasscast, and copper have been used as mold materials.

WEDNESDAY, NOVEMBER 6

Uranium Ingot Production at Atomic Energy Commission Feed Material Production Centers: B. J. Buntz, Mallinckrodt Chemical Works.

The production of uranium ingots at feed material production centers includes both the preparation of the melting stock and the melting and casting of this stock into ingot form. This paper discusses the various steps in converting uranium tetrafluoride to metal, conditioning this metal to prepare it for the remelt furnaces, and finally melting and casting the metal into ingots for feed to the rolling mill.

Induction Melting of Uranium Base Alloys: N. J. Carson, Argonne National Laboratory.

One of the simplest methods mechanically for melting uranium-rich alloys in vacuo is induction melting. With the proper mechanical and electrical equipment available, the limiting factor in induction melting is the temperature to which the melt must be raised. If the alloy additions increase the melting point of the charge beyond the satisfactory operating range of the crucibles available, induction melting is not satisfactory and recourse must be made to water-cooled crucibles and arc melting. Such is the case when melting alloys contain large percentages of zirconium, niobium, and tantalum.

Melting and Casting of U-Zr-Nb Alloys: N. J. Carson and J. E. Baird, Argonne National Laboratory.

Centrifugal Casting of U-Zr Alloy Rods: A. B. Shuck, Argonne National Laboratory.

The development at Argonne National Laboratory of methods and equipment for the centrifugal casting of fuel slugs for the Experimental Breeder Reactor I is described. Enriched uranium-zirconium alloy was melted and poured under high vacuum into precision copper molds, arranged radially about a vertical axis spindle, to produce radiation resistant fuel slugs.

Injection Casting of Uranium-Fissium Alloys Pins: F. L. Yaggee, J. E. Ayer, and H. F. Jelinek, Argonne National Laboratory.

The current interest in recycled fuels for use in power-breeder-type reactors has led to a study of the fabricating characteristics of the uranium-base fissium alloys. An injection casting technique has been developed at ANL which makes possible the production of EBR-II-type fuel pins from most fissium alloy compositions. This report describes the injection casting apparatus and its operation, and presents data which supports its feasibility as a fuel production process. The uranium-base fissium alloy used was artificially compounded to contain a nominal 4 w/o of fission products.

Arc Melting of Uranium-Rich Alloys: W. H. Britton and W. V. Haynes, Bettis Plant, Westinghouse Electric Corp.

The two basic arc-melting techniques consumable and non-consumable, have not been applied to production melting of uranium-rich alloys with great success. The major problems encountered involve: (1) control of macro-segregation caused by the freezing rate which has a detrimental effect on the corrosion resistance of the alloy, and (2) removal of contaminants normally found in excess in the raw materials. To date arc melting of uranium rich alloys has been limited to experimental melting of small ingots and as a pre-alloying melt to precede vacuum induction melting. However, significant advances are predicted toward production techniques with additional studies on control of feed and atmosphere, stirring mechanisms, and freezing rate control using refractory liners.

WEDNESDAY, NOVEMBER 6

Press Forging of Dingot Uranium: J. A. Fellows and H. J. Schaffer, Mallinckrodt Chemical Works.

The choice of the initial procedure in the hot working of uranium metal depends largely on the size and shape of the primary mass of metal involved. The uranium "dingot" (a coined word meaning "direct ingot"), created by the thermit reaction between UF_4 and Mg in a massive bomb, has been developed to provide metal of a high purity that can be hot-worked directly, avoiding the cost of remelting and casting to ingots. The shape of the dingot has been selected to promote the most favorable metal yield from the bomb reaction; this is a truncated cone that is a very close approximation of a right cylinder about 18 in. in diameter by 18 in. high. This regulus is suitable for either extrusion of forging but is quite unsatisfactory for primary rolling. This paper describes the forging practice employed in preparation for secondary rolling or extrusion.

Rolling of Uranium: G. S. Hanks, J. M. Taub, and D. T. Doll, Los Alamos Scientific Laboratory.

This report presents information concerned with the fabrication of uranium sheet. Starting with cast uranium plate, the metal was hot rolled at 600° to 625°C to some intermediate thickness. The semi-finished sheet was then warm-rolled (300°–340°C) to the final thickness. The characteristics of the finished sheet in respect to crystal orientation were to a considerable degree dependent upon the rolling schedules. Schedules using unidirectional rolling or various amounts of cross rolling with or without intermediate annealing were examined. From this experience three basic rolling schedules were selected. Results have indicated that these schedules will produce sheet satisfactory for a variety of forming processes.

The mechanical properties of the sheet as imparted by the several rolling schedules were examined. In some measure, these properties helped to guide subsequent changes made in the rolling schedules. The grain size of the sheet was affected by time and temperature of annealing, and the per cent reduction prior to annealing. Mechanical properties were appreciably altered by the method of annealing. Salt annealing tended to embrittle the metal; vacuum annealing improved the ductility.

9:00 to 10:30 am, Constitution Room

FERROUS METALLURGY
P. K. Koh and Michael Tenenbaum, Chairmen

Distribution of Boron in Gamma Iron Grains: R. M. Goldhoff, General Electric Co., and J. W. Spretnak, Ohio State University. (JOURNAL OF METALS, October 1957)

The distribution of boron in gamma iron grains as a function of temperature is studied, employing three experimental techniques: (a) grain growth in high-purity iron–carbon and iron–carbon–boron alloys; (b) X-ray parameter measurements on iron–boron alloys as a function of temperature; and (c) the metallographic test for the boron constituent. It is concluded that boron undergoes positive adsorption to gamma iron grain boundaries and that the temperature coefficient of absorption is positive.

Some Observations on 885° F Embrittlement: G. F. Tisinai and C. H. Samans, Standard Oil Co. (Indiana). (JOURNAL OF METALS, October 1957)

The hardening of several 24 to 30 pct chromium steels was studied at temperatures near 885°F. In alloys containing normal amounts of carbon, the temperature and time of preheat treatment affect the hardening, apparently because of destruction of potential hardening nuclei by carbide nucleation. This occurs to a lesser extent in decarburized alloys and does not occur at all if the carbon is stabilized by titanium or is sufficiently low. Nitrogen has an effect similar to that of carbon. Hardening does not occur in electrolytic chromium. Interference with the nucleation of the hardening

constituent also affects the optimum hardening temperature. On the basis of one neutron diffraction run, long-range ordering to any sizable amount does not appear to be a likely explanation for 885°F hardening. Thus, the evidence tends to substantiate the belief that 885°F hardening is the result of coherent precipitation of a chromium-rich phase, nature of which still is not entirely clear.

On the Occurrence of Oxygen in Cast Iron: Gustaf Ostberg, Falu Kopparverk, Sweden.

The oxygen solubility in cast iron has been estimated from existing information in the literature concerning equilibria between oxygen, carbon, and silicon in iron alloys. The oxygen contents computed range from 5 to 30 ppm depending upon alloy composition and temperature. Sampling methods and analyzing technique have been investigated. With application of these findings the oxygen content in cast iron of the malleable iron type was studied on spoon samples analyzed by vacuum fusion. When compared with the calculated solubility at equilibrium, the oxygen content in practice in most cases was found to follow the theoretical trends. Kinetic factors influencing this behavior are discussed as well as the occurrence of oxygen-bearing inclusions as observed in the microscope.

Hot-Pressure Bonding of Iron to Aluminum: A. Bartoszak, J. Bedell, and S. Storchheim, The Glenn L. Martin Co.

9:00 to 10:30 am, Cotillion Room

DIFFUSION
Cyril Wells and M. W. Mallett, Chairmen

Diffusion of the Elements of the IB and IIB Sub-Groups in Silver: A. Sawatzky, Franklin Institute, and F. E. Jaumot, Jr., General Motors Corp. (JOURNAL OF METALS, October 1957)

Data are given for the diffusion of the elements of the IB and IIB sub-groups in single crystals of silver. With the exception of those for mercury in silver, the data indicate that the activation energies for diffusion of the atoms of a given sub-group in the same solvent are similar, but the frequency factors differ. From this, it is concluded that atomic size, provided solid solutions are formed, probably does not affect the activation energy. The relation of the present results to several of the more popular generalizations concerning diffusion is discussed.

Diffusion of Mg, Si, and Mo in Nickel: R. A. Swalin, University of Minnesota, Alan Martin, Vanadium Corp. of America, and R. Olsen, University of Minnesota. (JOURNAL OF METALS, July 1957)

Diffusion rates of magnesium, silicon, and molybdenum were measured in nickel as a function of temperature. Activation energies, Q, and values of the frequency factor, D_0, were calculated for each system. The activation energies obtained were found to be close to that for self-diffusion in nickel with the exception of magnesium, for which the value was found to be about 10 kcal per g-atom less. The results are interpreted in accordance with Lazarus' theory of solute diffusion and with a model proposed by one of the authors.

Molecular Diffusion and Interphase Transfer in the Solid-Copper–Molten Lead System: J. W. Gorman, Standard Oil Co. (Indiana), and G. W. Preckshot, University of Minnesota.

Coefficients for diffusion of copper through liquid lead have been determined over a wide temperature range using the infinite column model. These have been found to be independent of the composition. Within experimental error no resistance to transfer was noted across the solid-liquid interface. The Stokes–Einstein equation represented the diffusion data best and permitted the calculation of the radius of the diffusing specie, the cupric ion.

Approximate Method for Calculations Using Concentration-Dependent Diffusion Coefficients: A. G. Guy and M. Golomb, Purdue University, and A. S. Yue, Dow Chemical Co. (JOURNAL OF METALS October 1957)

Standard methods are available for calculating the results of diffusion processes provided the diffusion coefficient is a constant. In fact, the diffusion coefficient changes radically with composition in most alloy systems and, therefore, the standard methods are not quantitatively applicable. It is shown that a correction can be made for the variation of the diffusion coefficient with concentration by employing a special coordinate transformation. Illustrative calculations for two types of variation of the diffusion coefficient with concentration show that the accuracy of this approximate method is on the order of 20 pct for large changes in the diffusion coefficient. The relation of the present method to that of Wagner is discussed.

9:00 to 10:30 am, Embassy Room

TITANIUM
(Session Based on Submission of Research Abstracts.)
F. D. Rosi and M. A. Steinberg, Chairmen

Analysis of Titanium Alloys by the Vacuum Fusion Method: H. Littman, R. P. Barber, and H. P. Munger, Syracuse University.

Analysis of hydrogen and oxygen in titanium and titanium alloys by the vacuum fusion method is quite common. Hydrogen presents few problems and thus most of the work in the literature has been concerned with the analysis for oxygen. The oxygen analysis of two commercial alloys, Ti-6Al-4V and Ti-4Mn-4Al, are considered, contrasting Walter's dry method with that using a platinum bath. The location of the alloying elements in the furnace at the completion of the run is noted and some conclusions as to the mode of breakdown of the oxygen compounds are given. In addition, gettering by the alloying elements is carefully considered. The apparatus used in this work was designed for high precision and for a study of the problem of gettering. The apparatus is equipped with a water-cooled furnace and an intermediate transfer pump and storage between the furnace and the measuring system so that cool furnace walls and the highest speed pumping could be achieved. The escape of alloying elements from the crucible is controlled by regulating the temperature of the crucible cover and the funnel with a movable grounded copper gauze screen. The gases hydrogen, nitrogen, and carbon monoxide are analyzed by first separating the hydrogen from the other gases using a heated palladium tube. After measuring the amount of hydrogen, the nitrogen and carbon monoxide are passed over hot copper oxide. The carbon dioxide is trapped in a liquid air trap and the nitrogen measured completing the analysis. A clear advantage to this analytical method is that the measurement of carbon dioxide in a McLeod gage is never necessary. The precision of the analysis is ± 3 per cent.

Electrical Resistivity Anomalies in Titanium-Oxygen Alloys: R. J. Wasilewski, E. I. du Pont de Nemours and Co.

The resistivity-temperature relationships have been investigated in solid solution titanium – oxygen alloys up to 31 atomic pct oxygen, between – 196 and 1000°C. The room temperature resistivity shows a maximum at 25 pct oxygen, decreasing rapidly on further increase of the oxygen content. Alloys containing between 15 and 25 pct oxygen show what is believed to be an order-disorder type transition at 700°K, and above that temperature become semi-conducting, with very small energy gap values. Higher alloys show another transition at 800°K, the nature of which is not clear. The two transitions observed appear to coincide respectively with the change of sign in the Hall constant

in pure titanium, and the heat content anomaly in a titanium-oxygen alloy recently reported.

The above anomalies are discussed in terms of their implications as regards the electronic structure. It is suggested that oxygen is an electron donor. Some possible energy band configurations are discussed.

Interaction of Oxygen with Dislocations in Alpha-Titanium and Its Effect on the Ductile-to-Brittle Transition: Devendra Gupta, New York University, and Sheldon Weinig, Materials Research Corp.

Internal friction techniques were used to study the oxygen atom interactions with dislocations in Bureau of Mines "superpurity" alpha titanium. The decrement as a function of both strain amplitude and concentration were measured. Calculations using the observed breakaway strain for a dislocation resulted in a value of 0.015 ev for the interaction energy between an oxygen atom and a dislocation in alpha Ti. A modification of the analysis by Cochardt et al permitted a calculation of the energy of interaction for the case of the hexagonal close-packed lattice. This value which was computed from the variation of the lattice parameters with oxygen content was determined to be 0.022 ev for an edge type of dislocation in alpha Ti.

The oxygen content required to fully saturate the decrement, i.e. no further decrease in the decrement with solute content, was approximately 1.5 atomic pct subsequent to an anneal at 800° C. The transition from ductile to brittle behavior as determined from tensile elongation tests occurred at approximately the same solute concentration. An identical temperature dependence of both the saturation point and the transition composition were found. It was suggested that the transition from ductile to brittle behavior was due to the adsorption of solute (oxygen) atoms at the dislocations. In view of the behavior of solute atoms relative to dislocations, i.e. the adsorption behaves according to the equation $C = C_0 \exp(G/kT)$, it was possible to predict that a high temperature – rapid quench treatment would result in a more ductile Ti-O binary alloy as this would decrease the number of oxygen atoms segregated at the dislocations. Typical of the corroboratory results obtained was an increase of 33 pct uniform elongation in a 0.2 atomic pct oxygen alloy.

Effect of Alpha-Beta Ratio on the Heat Treated Properties of Titanium Alloys: R. J. Quigg, E. L. Harmon, Jr., and A. R. Troiano, Case Institute of Technology.

Mechanical properties were evaluated in terms of transformation behavior in a series of quenched and aged titanium-vanadium alloys. The amounts of the alpha and beta phases in the quenched condition were quantitatively determined and their composition estimated from the equilibrium diagram. Subsequent aging behavior was predicted from appropriate TTT curves. It was found that at least 50 pct of the quenched structure should be metastable beta in order to obtain any sizable age hardening response. The greater the amount of vanadium present in this beta the more sluggish was the response. Each combination of solution temperature and cooling rate possessed a unique aging behavior. Coherent omega and a fine alpha precipitate tended to strengthen the alloy. Where large amounts of metastable beta were retained by quenching, omega and/or very fine alpha could not be tolerated without embrittlement, but where less than 50 pct of metastable beta was retained by quenching, these phases did not significantly impair ductility. A low yield to tensile ratio resulted when omega was present in a structure which contained less than 50 pct beta.

Where large amounts of the metastable beta phase were retained by quenching, the best combinations of strength and ductility were obtained at some intermediate aging time. Over aging in all cases resulted in lowering of strength and raising of ductility. The alpha phase was apparently tougher than the beta phase. The greater the amount of alpha, the higher was the Charpy impact energy. Accordingly, over aging improved impact properties. Strain hardening as evidenced by a high ratio of elongation to reduction in area was obtained in an alloy quenched from a solution temperature where the

composition of the beta phase was 16 pct vanadium. This strain hardening was attributed to deformation-induced transformation.

Grain Boundary Adsorption of Solutes and Its Effect on the Creep Properties of Alpha Titanium: J. Winter, New York University, and Sheldon Weinig, Materials Research Corp.

The grain boundary adsorption of substitutional solute elements in alpha titanium was studied using internal friction techniques. Bureau of Mines "superpurity" Ti was used as the solvent and the binary constituents were Al, V, Zr, Cb, and Au. The adsorption was studied as a function of both the bulk concentration of solute and the solution temperature. An Arrhenius type of equation was found to describe accurately most of the data. From the variation of the internal friction peak magnitude and the observed activation energy for grain boundary stress relaxation it was possible to calculate the interaction energy between a solute atom and the grain boundary. The value of the energy interaction, although varying as a function of the type of solute atom was in the range of 0.1 - 0.3 ev.

Grain boundary solute adsorption was observed to occur for alloying elements of both positive and negative size factors. The amount of adsorption was found to be dependent upon the degree of elastic misfit for the particular solute. Subscribing to the theory of their being energetically favorable sites at the grain boundary for solutes of both positive and negative size deviations, ternaries containing combinations of alloying elements were investigated. Cumulative effects were observed for the solute adsorption at the grain boundaries.

Corroboratory creep studies were performed in which the direct grain boundary contribution to the total creep strain was measured. It was found that the grain boundary contribution to creep varied as a function of the solute adsorption. Since a linear relation between the grain boundary elongation and the total creep strain is observed it is expected that the grain boundary adsorption of solutes having both negative and positive size factors will have a profound effect on the high-temperature creep characteristics of metals.

Elevated Temperature Characteristics of Internally Oxidized Titanium-Cerium Alloys: R. H. Hiltz, Jr. and N. J. Grant, Massachusetts Institute of Technology.

Solid solution titanium-cerium alloys, cold rolled to 0.010-in. thickness, and annealed, were internally oxidized to produce a fine dispersion of CeO_2 in the titanium matrix. The oxidized alloys were cut into sheet stress-rupture specimens and tested for rupture life at 426°C, 538°C, and 648°C. There was noted an improvement in strength over that of pure titanium, the internally-oxidized alloys showing curves with a much flatter slope on the log stress-log rupture life plot, characteristics of the stable metal-metal oxide class of alloy.

12:30 pm, Pent House, 42nd Floor

METALLURGICAL SOCIETY BOARD OF DIRECTORS LUNCHEON MEETING
J. C. Kinnear, Jr., President

2:00 to 5:00 pm, Grand Ballroom

SYMPOSIUM ON URANIUM AND URANIUM DIOXIDE
A. R. Kaufmann and J. M. Taub, Chairmen

Extrusion of Uranium: P. Loewenstein, Nuclear Metals, Inc.

Techniques for the extrusion of uranium differ considerably from those used for other commonly extruded metals, such as aluminum, magnesium, or copper, and their alloys. The reasons for these differences can be explained by properties peculiar to uranium and most of the other reactive metals. These properties are reviewed and the development of the extrusion technique explained in their terms.

Cold Working of Uranium: J. M. Taub, D. T. Doll, and G. S. Hanks, Los Alamos Scientific Laboratory.

Uranium can be cold worked as easily as many of the more common metals if the proper working conditions are observed. A transition temperature for uranium exists between 100°C (212°F) and 150°C (302°F). Uranium is quite ductile above this transition temperature and, wherever possible, all cold working operations should be performed at temperatures above 150°C. Uranium can be rolled, deep-drawn, swaged, and drawn into fine wire without much difficulty. At 2.5 pct strain, uranium exhibits a critical strain characteristic and large grains are observed after annealing. The annealing atmosphere affects the ductility of uranium at room temperature. Vacuum-annealed uranium has room-temperature ductility superior to that of salt-annealed uranium.

Fusion Welding of Uranium: E. L. Brundige, D. T. Doll, G. S. Hanks, and J. M. Taub, Los Alamos Scientific Laboratory.

Techniques for the fusion welding of uranium have been under development. Several methods of fusion welding have been investigated. The most satisfactory method developed was the inert-gas, shielded-arc method without the use of filler metal. Melting was accomplished by an electric arc maintained between the tungsten electrode and the piece being welded. The electrode and the fusion area were shielded by a flow of helium or argon issuing from the annular opening formed by the cup surrounding the electrode. Straight polarity direct current was chosen for fusion welding work since this type of current results in greater weld penetration at lower amperages and also provides a more stable arc during welding. Uranium properly welded by this method was free from porosity, cracks, and oxide inclusions. Uranium has been successfully fusion welded in thicknesses ranging from 0.010 in. to 0.500 in. using the tungsten arc, inert gas process. Surface condition and the purity of the gas used affected the weld soundness. Uranium weldments exhibited some distortion; residual stresses, however, appeared to be at a minimum due to the plasticity of uranium at temperatures above 150°C. The tensile and yield strengths of welded uranium joints exceeded the strength of the cast metal. Welding must be done in the flat position. Uranium cannot be welded in the vertical or overhead positions.

Powder Metallurgy of Uranium and Uranium Alloys: J. L. Zambrow, Sylvania-Corning Nuclear Corp.

The operation of a power reactor is more economical as the operating temperature increases, and/or as the life of the fuel increases. Natural wrought uranium is considered inadequate as a fuel for efficient power production because of its dimensional instability under irradiation even at relatively low temperatures (less than 600°C fuel temperature). Such elements must be removed from the reactor after relatively short exposures (total atom burn-up of less than 0.5 pct) because of the deformation that occurs during irradiation. Considerable effort has been directed toward improving the performance of the fuel element, by making it more stable dimensionally to increase its exposure time, and by making it suitable for operation at higher temperatures. This paper reviews some of the work that has been done on metallic elements.

Various Methods of Preparing Uranium Dioxide for Fuel Element Use: G. W. Tompkin, D. E. Rhodes, and C. M. Henderson, Mallinckrodt Chemical Works.

Two sources of uranium bearing materials are generally utilized in the preparation of uranium dioxide (UO_2) for fuel elements. Ura-

nium hexafluoride (UF_6), as produced in the gaseous diffusion plant at Oak Ridge, is one source and can be used to produce UO_2 with a U^{235} isotopic content varying from a natural U^{235} of 0.71 pct to enrichments of 90 pct U^{235} or more. Ore concentrates, consisting of mixtures of uranium compounds of natural (0.71 pct U^{235}) isotopic content and impurities, serve as the other source of uranium-bearing materials used in the production of UO_2 for fuel elements.

Uranium hexafluoride is currently utilized by the Special Metals (Commercial) Division of Mallinckrodt to produce UO_2 powders ranging in isotopic enrichment from a synthetic normal content of 0.71 pct to 93 pct or more of U^{235}. The large-scale production of natural UO_2 from ore concentrates is carried out at AEC-sponsored sites such as the Uranium Division of Mallinckrodt and the National Lead Company of Ohio. Where purified UO_2 is created as one of the steps in converting ore concentrates to high-purity uranium metal. Some physical and chemical properties of the type UO_2 used in the fabrication of the fuel elements for the Pressurized Water Reactor (PWR) and a description of various methods of producing UO_2 for fuel-element use are included.

Fabrication of Bulk Form Uranium Dioxide for Use as Nuclear Reactor Fuel: J. Glatter, Bettis Plant, Westinghouse Electric Corp.

The main process development and subsequent manufacturing effort for the high density bulk UO_2 fuel used in the blanket region of the PWR core was centered on the cold pressing and sintering method. This paper presents the Bettis Plant experience in evolving processes for fabricating slip cast, hydraulically extruded, and low compaction pressure cold pressed UO_2 of high density.

Fabrication of High-Density Uranium Dioxide Fuel Components for the First Pressurized Water Reactor Core: T. J. Burke, J. Glatter, H. P. Hoge, and B. E. Schaner, Bettis Plant, Westinghouse Electric Corp.

The development work leading to the establishment of a process for the manufacture of large quantities of high-density UO_2 fuel components on a production basis is presented. The fabrication process is described in detail.

2:00 to 5:00 pm, Constitution Room

TRANSFORMATIONS
W. M. Mullins and J. Washburn Chairmen

Micrographic Investigation of Precipitation in Lead-Tin Alloys: D. Turnbull and H. N. Treaftis, General Electric Co. (JOURNAL OF METALS, January 1958)

Precipitation of tin from lead-tin alloys (lead-rich) occurs by the nucleation and growth of hemispherical cells, which consist of tin lamellae interspersed in the depleted solid solution. We have investigated the nucleation and growth of these cells and the tin interlamellar spacing at various compositions and temperatures. The interlamellar spacing increases approximately as the reciprocal of the logarithm of the supersaturation ratio. For constant initial tin concentration, the concentration of cell nuclei increases with decreasing temperature to a limiting temperature-independent value. The kinetic results support the view that the cell growth rate is governed by the diffusion of tin along the cell boundary. In the main the results confirm our earlier deductions, drawn from resistometric and calorimetric data, about the precipitation mechanism.

Mechanism of Precipitation in an Alloy of Copper 2.5 Per Cent Iron: J. B. Newkirk, General Electric Co. (JOURNAL OF METALS, October 1957)

The precipitation process in an alloy containing copper + 2.5 pct iron was studied experimentally by means of X-ray diffraction and

hardness measurements and light and electron microscopic observations. It was concluded that γ-Fe and α-Fe precipitate simultaneously, γ-Fe dominating in the early stages. During later stages, the particles of γ-Fe dissolve, providing the copper lattice with iron atoms which diffuse to the more stable α-Fe particles. The α-Fe particles continue to grow until all evidence of the γ-Fe is gone.

Effect of High-Temperature Aging on the Development of Minor Phases in an Age-Hardening Nickel-Base Alloy: W. C. Bigelow, J. A. Amy, and L. O. Brockway, University of Michigan.

Specimens of Inconel-X alloy solution-treated at 2050° F and aged for periods of 1, 10, 100, and 1000 hours at 1200°, 1400°, and 1600° F have been examined by electron microscopy and by electron and X-ray diffraction. Four minor phases were identified: titanium nitride, niobium nitride, an $M_{23}C_6$ complex carbide, and the intermetallic γ' phase. The two nitrides were found in all of the aged specimens and in the solution-treated alloy; the γ' phase formed at all aging temperatures, while the $M_{23}C_6$ carbide formed only on aging at 1200° and 1400° F. Variations in the metallurgical properties of the alloy are correlated with the size and distribution of the γ' particles.

X-Ray Investigation of Recrystallized Aluminum: S. Weissman, Rutgers University.

A method combining X-ray microscopy and diffraction analysis has been applied to the study of the mechanism of recrystallization of 99.99+ pct aluminum. Evidence is obtained that primary recrystallization is a preferential growth of a few subgrains. It can be shown that the growing grain contains inclusions of fine subgrains of similar orientation, 1–2μ in size. These subgrains are not absorbed with increasing annealing time or temperature but exhibit rather a coarsening in size as well as in orientation difference. Thus, subgrain coarsening plus the inclusions of new subgrains of similar orientation give rise to an increase in the total orientation spread of the lattice of the growing recrystallized grain. The effect of the lattice strain set up by the sub-boundaries on the kinetics of secondary recrystallization is being considered.

Transformation Kinetics and Mechanical Properties of Zr-Mo Alloys: R. F. Dogmala, D. W. Levinson, and D. J. McPherson, Armour Research Foundation. (JOURNAL OF METALS, October 1957)

Alloys containing 1.3, 3.3, 5.4, and 7.5 pct Mo were prepared using high-purity molybdenum and sponge zirconium. Time-temperature-transformation curves were established for these alloys based on the resistivity vs. time of anneal of isothermally quenched rods. Tensile and impact bars of each alloy were heat treated by isothermal quench techniques as well as by quench and reheat treatments. These bars were then machined, tested, and the properties compared. Optimum properties could be developed in the 1.3 pct Mo alloy using the isothermal quench technique. The 3.3, 5.4, and 7.5 pct Mo alloys exhibited a brittle behavior irrespective of type of heat treatment. An ω or transition phase in the $\beta \rightarrow \alpha$ transformation was discovered which undoubtedly accounts for most of the brittleness observed. The ω phase has been tentatively indexed as tetragonal, $c/a = 1.45$. Mechanical properties of unalloyed sponge zirconium are presented for comparison.

Textures of Cold-Rolled and Recrystallized Crystals of Silicon-Iron: J. L. Walter and W. R. Hibbard, Jr., General Electric Co.

Silicon-iron crystals rolled in a direction nearly parallel to the 001 direction were examined to determine the relationship between the initial orientation, the cold-rolled texture, and the recrystallized texture. If the crystal has an original orientation such that the cube plane is within 30° of being parallel to the rolling plane, the recrystallization orientation will tend toward the (100) [001] orientation. On the other hand, if the (110) plane is nearly parallel

to the rolling plane, the recrystallization orientation will tend toward (110)<001>. If the orientation of the crystal falls in the overlapping area between the two groups, the recrystallization orientation will be either the (100)<001> or (110)<001> orientation, depending on whether the <001>-direction is parallel to or at an angle to the rolling direction, respectively. These results are consistent with those of Chen and Maddin on molybdenum.

Minor components present in the cold-rolled texture had the same orientation as both the mean recrystallization texture and the initial orientation of the crystal before it was rolled. These components may represent residual traces of the initial orientation, which serve as nuclei for the recrystallized grains. In addition, the rotation relationship between the major components of the rolled and recrystallized textures frequently involved axes which corresponded to the pole of the slip plane with the highest resolved shear stress thus presumably active during deformation. This relationship is similar to that previously found in the face-centered-cubic metals. Polycrystalline recrystallization textures in silicon iron may be rationalized on the basis of the components present in the cold-rolled texture and the available data on the kinetics of recrystallization of single crystals in relation to their cold-rolled and recrystallization textures.

Information on "Nuclei" for Secondary Recrystallization in Si-Fe: C. G. Dunn, General Electric Co., and P. K. Koh, Allegheny Ludlum Steel Corp.

Information on the nature of nuclei for secondary recrystallization has been obtained from microstructure, magnetic torque, and texture data before and after grain growth in silicon iron containing 3.23 pct Si. The cold-rolled textures of two single crystals were (111)<112>. The primary recrystallization textures consisted of two strong components near (120)<001> and (320)<001>, and two weak components near (111)<110> and (111)<110>. Qualitatively these four components were largely retained during grain growth. However, in one specimen the (111)<110> and (111)<110> components became strong, due to secondary recrystallization despite considerable simultaneous normal growth and some retention of the (120)<001> and (320)<001> components. In the other specimen normal grain growth predominated with good quantitative retention of the primary recrystallization texture. The results for secondary recrystallization could be explained in terms of oriented nuclei (i.e., large primary recrystallization grains from specific weak components of the texture) and the dependence of growth rate on driving force and boundary mobility. The presence of (111)<110> and (111)<110> type components in the secondary recrystallization texture when weak components of the same orientation were found in the primary recrystallization texture was considered as evidence for oriented nuclei. The occurrence of normal grain growth in both specimens indicated that the two specimens were probably very similar in most regions. However, the occurrence of secondary recrystallization simultaneously with normal grain growth in one specimen was considered to indicate that a small number of the largest (111)<110> and (111)<110> primary recrystallization grains were appreciably larger in this specimen than in the other. The larger size of such grains would increase the growth rate and reduce the induction period for secondary recrystallization.

Intermetallic Compounds in Titanium-Hardened Alloys: H. J. Beattie, Jr. and W. C. Hagel, General Electric Co. (JOURNAL OF METALS, July 1957)

Aging reactions in 25 pct Ni-15 pct Cr alloys of the A-286 type have been investigated using light and electron microscopy, X-ray and electron diffraction. Maximum dispersion hardening is provided by aluminum-poor, γ', η platelets are observed above 1400° F. G phase is a globular nickel-titanium silicide resulting from grain-boundary segregation, bulky Laves or σ phases appear depending on whether there is an excess of titanium or aluminum. Cellular precipitation involving a new phase occurs in vacuum-melted A-286 of negligible silicon content. Calculated Patterson-Harker sections show that the interatomic distances in G phase are not short.

2:00 to 5:00 pm, Cotillion Room

GENERAL METALLURGY
M. E. Fine and H. H. Chiswick, Chairmen

Precipitation and Magnetic Annealing in a Copper-Cobalt Alloy: J. J. Becker, General Electric Co.

A number of magnetic properties have been observed during the course of aging in Cu-Co alloy. In particular, the effect of a field during aging in producing magnetic anisotropy is shown to occur entirely during the growth of the particles, after the precipitate is complete. The picture of the precipitation process as one in which the particles pass through regions of characteristically different magnetic properties as they grow in size supplies a point of view that is consistent with all of the varied phenomena observed.

Processing and Properties of Cobalt-Platinum Permanent Magnet Alloys: D. L. Martin, General Electric Co.

The results of processing and heat treatment studies of 40 to 60 atomic pct cobalt-platinum alloys are presented. The permanent magnet properties have been found to be related to the composition, the solution temperature, the cooling treatment from the solution treatment, and the final ordering treatment.

The best properties of 4700 oersteds, coercive force and nine million gauss-oersteds, energy product were obtained on an alloy near the 50 atomic pct composition by controlled cooling and aging.

Elimination of Magnetic Effects in Beryllium-Copper: Harold Bernstein, United States Naval Gun Factory.

Nitrides of Silicon: W. D. Forgeng, Electro Metallurgical Co., Div. of Union Carbide Corp., and B. F. Decker, General Electric Co.

X-ray data are given for the two modifications of the nitride Si_3N_4, an oxynitride of silicon, Si_2ON_2, and a material prepared by fusion of commercial silicon nitride. The pattern for pure-α-Si_3N_4 is less complex than that reported in previous investigations and has been indexed on a hexagonal ($a = 7.758$, $c = 5.623$ Å) rather than orthorhombic cell. β-Si_3N_4 and the fused material (called Si_3N_4) also have hexagonal structures (β-Si_3N_4: $a = 7.603$, $c = 2.905$ Å; Si_2N: $a = 4.534$, $c = 4.556$ Å) which appear to be related to that of α-Si_3N_4. The pattern of the oxynitride is quite complex, but it can be satisfactorily indexed as orthorhombic ($a = 5.458$, $b = 9.677$, $c = 4.853$ Å). The dissimilar patterns reported in the literature for the germanium nitride, Ge_3N_4, can be rationalized by analogy with silicon nitride as being those of mixtures of two forms of the germanium nitride Ge_3N_4.

CsCl-Type Ordered Structures in Binary Alloys of Transition Elements: T. V. Philip, Crucible Steel Co. of America, and P. A. Beck, University of Illinois. (JOURNAL OF METALS, October 1957)

X-ray diffraction results indicate that in the VFe alloy, the b.c.c. disordered structure can be almost completely retained by quenching from 1250° C. On annealing at 600° C, the disordered b.c.c. structure transforms into a CsCl-type ordered structure before practically any of the stable sigma phase is formed. The increasing stability of the CsCl-type ordered structure from CrFe to VFe to TiFe indicates that the A-B bond increases in strength, as compared with the A-A and B-B bonds. This is accompanied by increasing brittleness, increasing lattice contraction, and the disappearance of ferromagnetism. It is probable that the increasingly strong A-B bond results from a quasi-ionic bond component due to electron transfer.

WEDNESDAY, NOVEMBER 6

Atomic Size Effects in Cr_3O-Type Structures: M. V. Nevitt, Argonne National Laboratory.

The results of a search of a number of binary systems for the Cr_3O-type, or β-tungsten, phase are reported. The relation of atomic size to the stability and to the lattice parameter of the phase is developed, and the connection between the position of the component elements in the Periodic Table and their Cr_3O-type phase-forming tendencies is discussed.

Some Internal Friction Studies in Niobium: R. W. Powers and Margaret V. Doyle, General Electric Co. (JOURNAL OF METALS, October 1957)

Carbon has been found to diffuse in niobium at a slightly more rapid rate than nitrogen. At one cps, that internal friction peak which arises from the stress-induced ordering of carbon in niobium is found at 268° C while the nitrogen peak occurs at 285° C. The diffusion coefficients are:

$D = 0.5046 \exp(-33,399/RT)$ for carbon in niobium and

$D = 0.0872 \exp(-34,899/RT)$ for nitrogen in niobium.

The carbon peak in niobium is very unstable; the height declining rapidly with time in contrast to the nitrogen peak. The ratio of the height of the nitrogen peak to the concentration of nitrogen in solid solution (expressed in wt pct) was found to be 9.33, in good agreement with previous work. The internal friction in high-purity niobium was found to be a sensitive function of the strain amplitude at which the damping was measured.

Effect of Crystal Orientation, Temperature, and Molten Zone Thickness in Temperature-Gradient Zone Melting: J. H. Wernick, Bell Telephone Laboratories. (JOURNAL OF METALS, October, 1957)

A strong orientation effect has been found for molten Al-rich wire zones traversing single crystals of germanium. If the intersection of a {111} plane with the plane of wire-travel is oblique to the wire, the wire breaks into segments that lie parallel to the line of intersection. But if the line of intersection is perpendicular or parallel to the wire, the wire remains straight. This crystalline anisotropy has been utilized to make highly parallel npn junctions using Al-rich wire zones in Ge. The rate of zone movement increases unusually rapidly with temperature and with diameter of the wire zone. These findings suggest that the rate-controlling factor in these experiments is not diffusion in the liquid zone, but the solution rate at the hotter interface. Diffusion may become the limiting process at higher temperatures and lower temperature gradients.

2:00 to 5:00 pm, Embassy Room

SYMPOSIUM ON THE RELATION OF STRUCTURE AND HIGH-TEMPERATURE PROPERTIES
R. W. Guard and I. Servi, Chairmen

Young's Modulus of Magnesium Alloys at Elevated Temperatures as a Function of Metallurgical Variables and Microstructure: R. W. Fenn, Jr., Dow Chemical Co.

The measurement of Young's modulus of several experimental and commercial magnesium alloys at temperatures between 75 and 800° F permit classifying these alloys into two groups: (1) those containing 1 to 3 pct thorium or rare earths and having relatively high moduli at elevated temperature, and (2) those having significantly lower moduli at elevated temperature. The difference in the behavior of these two classes of alloys is discussed in terms of alloy content and the type, amount and distribution of intermetallic compound and its effect on

anelastic grain-boundary relaxation. The effects of: cold work (as pre-compression and cold rolling), changes in grain size; and amount, size and distribution of compound in both classes of alloys are illustrated metallographically and correlated with accurately determined values of Young's modulus at elevated temperature. This study defines useful metallurgical methods of controlling the magnitude of this important design property at elevated temperatures in magnesium alloys.

Role of Recovery and Recrystallization on the Creep Rupture Behavior of 2S Aluminum: M. B. Happ and N. J. Grant, Massachusetts Institute of Technology.

The influence of recovery processes on ductility and the nature of fracture during creep at elevated temperatures was investigated in annealed commercially pure 2S aluminum. The normal transition to intercrystalline cracking and failure with increasing temperature, with attendant decrease in ductility, is shown to reverse itself with further increase in temperature or decrease in strain rate, as certain recovery processes become operative. With this reversal there is an increase in ductility. The inhibiting effect of intercrystalline cracking on recrystallization is demonstrated.

Study of Structural Modifications of Steel During High-Temperature Deformation: C. Crussard and R. Tarhankar, Institute de Recherches de la Siderurgie, St. Germain-en-Laye, France.

Two steels have been investigated: one ferritic (decarburized Armco iron) and one austenitic (low-carbon Ni-Cr 35-10 steel). Mechanical tests have been performed at various temperatures and various rates of deformation on samples of different grain-sizes; tensile tests between 20° C and 750° C, creep tests between 550° C to 900° C, torsion tests between 1000° C to 1200° C, internal friction measurements from 20° C to melting point. In most cases, a comparison of the behavior of fine- and coarse-grained samples enables a determination of equicohesion temperature under both aspects: resistance to glide and rupture.

In order to explain the mechanical behavior of these metals, the structural modifications have also been studied by several methods: micrography of sample surface, metallographic sections, microfractography and X-rays. The part played by the following phenomena have been investigated: slip-band formation, grain-boundary glide and migration, polygonization and recrystallization, intergranular fissures formation. The competitive actions of polygonization and recrystallization are discussed, as well as their influence on fissure formation.

Role of Subgrains in Creep: J. E. Dorn and L. Shephard, University of California.

The genesis of subgrains includes a study of single crystals, slip bands, deformation bands, kink bands and folds, role of polygonization, and the role of grain boundary shearing. The effect of these factors on subgrain structure was studied: strain, stress, temperature, temperature-compensated time, influence of stress changes, steady-state structures, and subgrains produced at low-creep stresses.

Role of Grain Boundaries in Creep: E. R. Parker, University of California.

We have made creep tests on polycrystalline copper having a variety of grain sizes and with controlled amounts of preferred orientation. The boundary angle between adjacent grains plays a controlling role in creep. Grain size effects and boundary angle effects are closely interrelated. This new work clearly shows the importance of boundary angle (i.e. degree and kind of preferred orientation).

THURSDAY, NOVEMBER 7

7:30 am, Cub Room

IMD POWDER METALLURGY EXECUTIVE COMMITTEE BREAKFAST MEETING
F. V. Lenel, Chairman

9:00 am to 12:00 m, First Floor Foyer

REGISTRATION

9:00 am to 12:00 m, Embassy Room

DEFORMATION AND RELATED PROBLEMS
(Session Based on Submission of Research Abstracts.)
M. R. Achter and R. L. Smith, Chairmen

Role of Polygonization in Creep: R. W. Guard, General Electric Co.

Dislocation etch-pit patterns in a number of specimens of nickel subjected to creep deformation at elevated temperatures have been examined. Etch-pit patterns show two distinct morphologies as follows:

1. Broad bands of high density of pits showing some sub boundaries within the bands.

2. Single sub boundaries (and some random pits) between the broad bands. The direction of the boundaries is generally normal to the bands.

The changes in the overall patterns of the specimens with time (and strain) during a creep test show that the broad bands form on initial loading (or early in the creep test) and the single boundaries increase in number (and density) during the creep straining. These effects have been examined as a function of stress and temperature for creep strains from 0.002 to 0.05.

A model is proposed for creep deformation in which the rate of creep is dependent on the rate of generation and the mobility of dislocations in the dislocation structure. The rate of generation and mobility are dependent on the magnitude of the long range stress fields of the dislocations (Taylor's model of strain hardening). The stress fields are lowered by annihilation and/or polygonization of the dislocations generated. Taylor's model of strain hardening is used although its specific details are not necessary for the hypothesis. The predictions of the model with respect to the effects of temperature, stress and prior dislocation structure are discussed and the observed morphologies of the dislocation structure rationalized.

Comparison of the Creep-Rupture Properties of Nickel in Air and Vacuum: P. Shahinian and M. R. Achter, U. S. Naval Research Laboratory.

In a comparison of the creep-rupture properties of nickel in air and vacuum at 1200° and 1500°F there is a reversal in relative strengths with variations in stress level for strain rate). At low stresses the creep and rupture strengths are better in air while at high stresses they are better in vacuum. The reversal point at which the specimens tested in air become more creep resistant than in vacuum is moved to a shorter time as the test temperature is raised from 1200° to 1500°F. At very low stresses, specimens tested in air at 1500°F undergo marked strengthening attended by extensive oxidation and virtual cessation of creep. At high stresses the relative creep strengths of vacuum- and air-tested specimens may be reversed during the course of the test. In the early stages the specimen in vacuum has the higher creep rate but the one in air is creeping faster in the latter stages.

A tentative mechanism involving two competing processes is considered that qualitatively explains these observations. One process, oxidation strengthening, is dominant at low creep rates while the other, reduction of strength due to lowering of surface

tension, is dominant at high creep rates. The atmosphere strengthening involves internal oxidation, which is a slow diffusion process and, therefore, in high creep rate tests the competing process is controlling. It is proposed that the reduction of surface tension in air compared to vacuum facilitates crack propagation and after cracking is initiated, in short-time tests, the air specimen starts to creep at a faster rate than the one in vacuum.

Deformation of Rhenium: A. T. Churchman, Associated Electrical Industries, Ltd., London, England.

The marked work hardening of rhenium, which renders it difficult to fabricate the metal, is unexpected. It may arise because room temperature is low relative to the melting point of rhenium or more likely from some peculiarity in its deformation mechanism. Examination of coarse polycrystals under compression showed extensive $10\bar{1}2$ and $11\bar{2}x$ twinning together with $(10\bar{1}0)$, (0001) and $(10\bar{1}1)$ slip as in other hexagonal metals. The $11\bar{2}1$ twins were accompanied by very marked and extensive accommodation bands. Only certain orientations appear to work harden rapidly, the maximum effect being in the accommodation on bands to $11\bar{2}1$ type twins. Grain boundary sliding takes place at room temperature where there is a slip system nearly parallel to the boundary. Fracture occurs as ductile tearing at grain boundaries.

Internal Friction in Aluminum at Low Temperature: A. J. Filmer, G. J. Hutton, and T. S. Hutchison, Royal Military College of Canada.

Recent ultrasonic measurements by a semiautomatic process of the internal friction of 99.992 pct aluminum as a function of temperature have revealed a number of previously unreported attenuation maxima at temperatures between 90°K and 300°K. These maxima are unlike the cold work induced peaks, first reported by Bordoni. They appear to be due to an avalanche process that can perhaps be associated with the breakaway of dislocations from minor pinning points. An interesting equality exists between the ratio of the peak temperatures and the orientation factor relating the different close-packed directions on the slip plane.

Deformation of Aluminum Single Crystals at −77 Deg. C: A. Kelly and S. Sato, Northwestern University.

Stress-strain curves have been obtained for single crystals of pure aluminum at −77°C. This temperature has been chosen because the stress-strain curve shows three stages and also slip lines may still be seen clearly under the optical microscope. Measurements have been made of the lengths of the slip traces produced on a surface containing the slip direction (side surface) and on a surface perpendicular to this (top surface). The variation in the length of the slip traces on both surfaces has been studied as a function of strain and of crystal orientation. It is confirmed that on the top surface cross slip is first seen when the stress-strain curve becomes concave to the strain axis. The number of cross slip sites observed per unit area then increases with increasing stress.

The slip trace lengths are taken to be a measure of the distance between barriers encountered by dislocation loops expanding from a source. This distance decreases throughout the deformation. The results are discussed in terms of the interference in the motion of dislocations on the primary slip system by those in secondary systems.

Resistivity Recovery in Cold-Worked Aluminum: H. R. Peiffer and I. R. Kramer, Rias, Inc.

Aluminum (99.984) tensile specimens with an 1/8 in. and 3/16 in. diameter were strained various amounts in liquid nitrogen. Resistivity measurements were made at this temperature before and after straining and finally after the specimens were allowed to anneal at 25°C or −78°C for a number of hours. These measurements show that the resistivity recovered by annealing at 25°C or −78°C was directly proportional to the total increase in resistivity obtained

after the initial stress. Further, the recoverable resistivity was directly proportional to the resistivity remaining after the annealing treatment. The ratio of the decrease in resistivity to the residual resistivity for specimens annealed at −78°C was the same as that for specimens annealed at 25°C. For specimens which had been cold-worked before testing, the ratio of unrecoverable to recoverable resistivity was the same as that for annealed specimens. This ratio was about 0.64. The results indicate that the recoverable resistivity is due to the annihilation of point defects while the unrecovered resistivity is associated with residual point defects, and possibly dislocations to a smaller degree.

Mechanical Behavior of Microcrystals: W. W. Webb and W. D. Forgeng, Electro Metallurgical Co., Div. of Union Carbide Corp.

Bend tests have been carried out on some precipitated crystals chemically extracted from two-phase alloys and on some whiskers and other small crystals grown from liquid or vapor phases. Crystals of β-manganese, Mn_6Si_1, α-Si_3N_4, α-Al_2O_3, Cr_3C_2, Cr_2N, chromium, and Fe_3C were studied. All of these materials could be bent to relatively large elastic strains, and the calculated strengths of most of them approach theoretical values. The results are discussed in some detail, and it is concluded that a distinction should be made between those crystals eventually failing by brittle fracture and those that fail by plastic deformation. It appears that although metal whiskers are unique because of the absence of edge dislocations, the occurrence of other crystals with nearly theoretical strength is not unusual. There is some evidence that dislocations have little effect on the mechanical properties of hard or brittle microcrystals.

Motion of Dislocations Opposed by a Frictional Force: H. R. Peiffer, Rias, Inc.

The equation of motion for a screw dislocation in an elastic medium is solved when the dislocation experiences a retarding frictional force. The solution is extended to describe the motion that arises when an applied force also acts on the dislocation. A solution is obtained for three different applied forces, i.e., (a) a constant, (b) a force increasing linearly with time, and (c) a sinusoidal force.

The solutions indicate that the ratio of the amplitude of the applied load to the coefficient of friction is very important in determining the magnitude of the dislocation displacement. When the applied load is sinusoidal, its frequency also enters this ratio.

The solutions indicate that there may be a direct connection between the frictional force and the delayed yielding of metals. From the solutions, there is an indication that the important variables to consider in the problem of fatigue are applied load, frequency of oscillation and, finally, the coefficient of friction. There is no good estimate of the magnitude of the frictional force constant, α. It is suggested that internal friction may afford a means of determining it.

Viscous Dislocation Motion in LiF: J. J. Gilman and W. G. Johnston, General Electric Co.

Direct observations of dislocation motion in LiF crystals show that there is a quasi-viscous resistance to dislocation motion in this material. This resistance does not involve dislocation interactions, but occurs for dislocations moving in dislocation-free regions of the lattice. The viscosity increases with impurity content, with neutron bombardment, and with decreasing temperature. The velocity of a dislocation increases exponentially with stress for stresses greater than a critical stress.

Effect of Heat Treatment on the Coercive Forces of Aluminum-Iron Alloys in the Ordering Region: K. Foster and D. Pavlovic, Westinghouse Electric Corp.

Optimum heat treatment conditions to produce low coercive force values in alloys in the region of 16 at pct aluminum iron

have been determined. The heat treatment of 16 pct aluminum-iron is dependent upon order-disorder reactions which take place in the aluminum-iron system between 19 and 28 wt pct aluminum. A high-temperature heat treatment followed by a quench from above the Fe_3Al ordered region is required to obtain low coercive force values in alloys from 14 to 17 pct aluminum iron. Ring laminations punched from 0.007 in. thick sheets of 15.6 to 16.8 pct aluminum iron were used for heat treatment and magnetic testing. The heat treatments consisted of heating at an elevated temperature for two hours, furnace cooling to 600° C, and quenching in water at room temperature. Various heat treatment atmospheres were used. A plot of coercive force versus aluminum content is given for each heat treatment. For a given heat treatment the coercive force decreases with increasing aluminum content. Alloys containing ternary additions were also studied. Microstructures show that the heat treatment controls both the grain size and the distribution of inclusions, which in turn affect the magnetic properties. An attempt is made to correlate some of the results of this investigation with a proposed revision in the order-disorder region of the aluminum-iron phase diagram. This new phase diagram shows that 16 pct aluminum iron undergoes two order-disorder reactions with increasing temperature, as opposed to a single order-disorder reaction shown previously. The effect of sheet thickness on the coercive force of 16 pct aluminum iron is also shown; for a given heat treatment, the coercive force increases with decreasing sheet thickness.

9:00 am to 12:00 m, Madison Room

SYMPOSIUM ON POWDER METALLURGY
F. V. Lenel and G. L. Bibbins, Chairmen

Study of Sintering of Aluminum Oxide: George Kuczynski, University of Notre Dame.

The progress of sintering of pure aluminum oxide spheres was studied by measuring the "necks" grown between spheres of this material during heating at temperatures ranging from 1700–2000° C in various atmospheres. Thus far, it has been found that the mechanism of sintering of aluminum oxide in dry hydrogen, helium, vacuum, or air is one of volume diffusion. The rates of sintering in dry hydrogen were observed to be much greater than in other atmospheres. This is probably due to the additional vacancies created in the crystal during the process of reduction of Al_2O_3 by H_2. In the presence of impurities, such as tungsten or molybdenum oxides, in the sintering atmosphere, the Al_2O_3 spheres were observed to sinter by a mechanism of viscous flow. The impurity oxides dissolving in Al_2O_3 form a glass or liquid layer on the surface of the particles.

Another interesting effect observed during the sintering of Al_2O_3 particles in dry H_2 was the gradual transformation of the spheres into polyhedra of hexagonal symmetry. This phenomenon, although not caused by sintering but definitely influencing its progress, will also be discussed.

Rate of Infiltration of Metals: K. A. Semlak and F. N. Rhines, Carnegie Institute of Technology.

The initial rates of the capillary rise of liquid copper and of liquid lead in iron and iron-copper compacts, and of liquid silver in copper compacts has been measured and shown to conform to the equation:

$$h = \frac{\gamma}{\eta}\sqrt{\frac{1}{2}\,Rc\,\frac{\gamma}{\eta}\cos\theta}\;t$$

where Rc is one quarter of the mean interparticle distance, γ the surface tension of the liquid phase, θ the liquid-solid contact angle, η the viscosity of the liquid phase, t the time of infiltration and 1/2 a correction factor accounting for the bending of the capillary channels. This equation, which appears to be valid when wetting occurs and when the particle size of the compact is below about 80 mesh, describes a parabolic time-height of rise relationship, which was employed in the examination of the influences of such variables as: powder size, extent of presintering of the compact, atmosphere

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and temperature of infiltration. It was thus shown that there is an increase in the size and fluid carrying capacity of the interparticle channels at the beginning of presintering; subsequently the channels shrink. It was also demonstrated that the time elapse during the first stage of ordinary liquid phase sintering (i.e. the liquid flow stage) is of the order of 10^{-3} seconds.

An Investigation of the Effect of Specific Surface Area of Certain Iron Powders on the Properties of Hot-Coined Specimens: D. P. Ferriss and J. G. Byrne, Stevens Institute of Technology.

The effect of the specific surface area of three commercial grades of iron powder on the mechanical properties of hot coined specimens was studied. The grades used were electrolytic, sponge and reduced atomized iron powder. Each type of iron powder was studied in the range of −100 + 150 mesh and −270 + 325 mesh. Specific surface area was measured by air permeability. A qualitative correlation was obtained between powder surface activity as measured by oxidation at 1000° F and specific surface area as measured by air permeability.

The hot coined mechanical properties studied were ultimate tensile strength, pct elongation, and hardness, both in the as-coined and the coined and annealed conditions. Macrophotographs (50x) of the powders and microphotographs (250x) of the resulting structures were analyzed. Ultimate tensile strength, as hot coined, increased consistently with increasing specific surface area of the powder used. The overall increase amounted to over 15 pct as specific surface area increased from 0.13 meters^2/gm. to 0.52 meters^2/gm. The tensile strength of the hot-coined iron powder was equal to, or in excess of that, of commercial wrought iron of similar composition. Elongation was less, however. It is felt that the annealing process used brought about migration and ordering of lattice defects and lowering of interfacial energies due to grain growth with the consequent lowering of ultimate tensile strength and hardness. Prior to this annealing process, hardness was also noted to increase with increasing specific surface area of the powder used. In both the as-coined and the coined and annealed conditions it appears that finer grain size is produced by higher values of specific surface area of the initial powder. Specific surface area is not difficult to measure by air permeability and may offer a more discriminating means for predicting the mechanical properties of hot coined iron powders than more conventional methods such as particle size, particle morphology, or apparent density. (Note: The minimum density of all specimens was 98.5 pct of the theoretical density of iron.)

Some High-Temperature Properties of Nickel and Cobalt Alloy Powder Extrusions Containing Non-Metallic Dispersions: C. G. Goetzel and Eric Gregory, Sintercast Corp. of America.

A technique involving sheathed extrusion has been established for the production of very low-porosity composite materials from powder blends. The experimental materials described consist of 80/20 nickel-chromium and cobalt alloy matrices with various hard phase additions.

Several methods of obtaining a uniform dispersion of a hard phase throughout a ductile metal matrix are reviewed. The method of mixtures, i.e. the direct blending of the soft and hard constituents, has been the principle one employed in this work, although materials have also been produced by chemical deposition of nickel on a blend of chromium and the hard phase additum agent in the powder form.

Stress rupture tests on the extruded materials were carried out at both 1500° F and 1800° F and these showed that the high-temperature strength of the matrix could be increased considerably with certain oxide and carbide additions.

The data reported also include high-temperature ductility values and the results of room temperature impact, density and hardness tests.

The results of optical and electron microscopy examinations reveal the variations in structure which have resulted from changes in the conditions and methods of manufacture.

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Development of Superior Cobalt-Base Alloys by Hot Coining Metal Powders with Minor Additives: E. B. Wilson, D. P. Ferriss, and G. J. Comstock, Stevens Institute of Technology.

The hot coining of metal powders to dense, high quality, heat treatable parts offers a method by which the effects of minor unconventional additions of different elements or compounds on the properties of a base alloy may be studied. Such studies are possible even if the added materials are incompatible and fabrication by conventional melting, casting, and forging techniques is precluded. The hot consolidation of a porous metal aggregate has been found applicable to not only forgeable alloys but also nonforgeable compositions.

Compared to the precision-cast material, hot coined unmodified alloy X-40 has demonstrated that: (1) the 1500° F stress-rupture and tensile properties of both materials are equivalent, (2) the hot coined product is superior in tensile strength and ductility at room temperature, and (3) the hot coined material is fine grained (ASTM 4-6) and free of large or segregated carbides with a microstructure controllable by heat treatment.

Additions in the range of 0.25 to 5 wt pct of TiC, WC, ZrB_2, CrB_2, TiB_2, B, and $MoSi_2$ to hot coined X-40 alloy were investigated. Beneficial effects on stress-rupture levels were obtained with almost all of these compounds. The effects contributed by the metallic diboride additions were believed due to the associated boron. Subsequent testing substantiated this hypothesis. As much as 100° F increases in stress-rupture levels at 1600° F were obtained at no sacrifice in ductility. This strengthening in the boron modified material was essentially stable over a range of 0.25 to 1 wt pct boron. Fatigue data at 1600° F and 10,000 cpm indicate an endurance limit of 30,000 psi to 35,000 psi at 10^8 cycles for the boron modified material. A mechanism for strengthening was hypothesized but not concluded.

12:00 m, Madison Room

POWDER METALLURGY LUNCHEON
F. V. Lenel, Chairman

2:00 to 5:00 pm, Embassy Room

EQUILIBRIUM STUDIES
L. A. Willey and J. O. Betterton, Jr., Chairmen

Delta Phase Field of the Uranium-Zirconium Equilibrium Diagram: J. F. Duffey and C. A. Bruch, General Electric Co. (JOURNAL OF METALS, January 1953)

On the basis of metallographic and cooling-rate studies of 15 uranium-zirconium alloys, an equilibrium phase diagram of the delta phase region has been constructed.

Constitution of the Uranium-Rich UNb and U-Nb-Zr Systems: A. E. Dwight and M. H. Mueller, Argonne National Laboratory.

Nature of the Nickel-Chromium System: R. O. Williams, The Cincinnati Milling Machine Co. (JOURNAL OF METALS, October 1957)

An investigation has been carried out on the Ni-Cr system. These results show that the recent version of the phase diagram of Grant and co-workers is in error. The chromium-rich alloys undergo rapid precipitation. Solubilities of Ni in Cr and Cr in Ni are also reported.

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Activity Measurements in the System Iron-Chromium: C. L. McCabe, R. G. Hudson, and H. W. Paxton, Carnegie Institute of Technology. (JOURNAL OF METALS, January 1958)

Activities of iron and chromium in their binary system have been measured by the Knudsen orifice technique. The system is close to ideal at 1200 - 1250° C with slight positive deviations. The effect of this on the liquidus and solidus is discussed and these are calculated for two limiting assumptions. The vapor pressure of pure iron, pure chromium, and one alloy is compared with that obtained by the Langmuir free evaporation technique. The results agree, indicating a vaporization coefficient close to 1.

A Thermodynamic Study of Liquid Pb-Zn Solutions: F. D. Rosenthal, G. J. Mills, Jet Propulsion Laboratory, California Institute of Technology, and F. J. Dunkerly, Rolle Manufacturing Co. (JOURNAL OF METALS, January 1958)

Activities of lead-zinc alloys were obtained by the reversible electrode-potential method in the homogeneous and heterogeneous liquid solutions between 400° and 650° C. Free energies and heats and entropies of mixing were calculated from these data. Phase boundaries were determined from the electromotive force results by standard thermodynamic methods. Intersection of the calculated Pb-rich and Zn-rich liquidus curves with the experimental and calculated liquid immiscibility boundaries fixed the monotectic and eutectic points. The results are in good agreement with published phase diagram studies and the electromotive force data are also supported by the values obtained by Kleppa. The observed large positive deviations of the activities from Raoult's law and the large positive enthalpies describe the extreme non-ideal behavior of the liquid solutions. Such deviations are assignable to atom size differences and predict the grouping of like atoms and consequent immiscible liquid behavior upon cooling.

High temperature data obtained by vapor pressure measurements and associated thermodynamic arguments were used to estimate the maximum of the immiscibility gap. This was found to be in the vicinity of 900° C, approximately 100° higher than the recent work of Seith and Johnen. Employing the experimental enthalpy data at the equimolar composition, the calculated elastic strain energy of a solid alloy yielded a value which affords confidence in the theoretical Varley equation.

Solid Solubility of Uranium in Thorium and the Allotropic Transformation of Thorium-Uranium Alloys: W. B. Wilson, A. E. Austin, and C. M. Schwartz, Battelle Memorial Institute. (JOURNAL OF METALS, January 1958)

High-temperature X-ray diffraction studies were conducted with thorium-uranium alloys with up to 10 wt pct uranium. The solid solubility of uranium in thorium as a function of temperature was determined by the method of lattice parameters. Thorium will dissolve up to 2.5 wt pct uranium at 950° C, 4.5 wt pct at 1150° C, and 7.5 wt pct at 1250° C. Determinations were made of the temperature of the transition of thorium and of the effect of uranium upon the transition. The alpha-to-beta transition for thorium was observed to occur at 1339 ± 20° C. Mean coefficients of expansion were calculated for thorium and two alloys and for ThO_2 in contact with the thorium using X-ray lattice-parameter data. Values obtained at 950° C for thorium and ThO_2 were respectively, 12.1 and 9.40×10^{-6} per C. Impurities obtained during the X-ray exposure were identified by diffraction and were essentially ThO_2 and ThC with two additional unknown phases being detected. The effect of the impurities upon the results is discussed.

Liquid Miscibility Gap in the Quaternary System Fe-Cu-S-C at 1450° C: D. L. Douglass, Ohio State University.

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Uranium-Columbium Alloy Diagram: B. A. Rogers, D. F. Atkins, E. J. Manthos, and M. E. Kirkpatrick, Iowa State College.

A phase diagram of the uranium–columbium alloys is presented. The apparatus and the procedures used in obtaining data are described. Data from which the diagram was drawn are given in tabular and graphic form.

2:00 to 5:00 pm, Madison Room

TRANSFORMATIONS AND ALLOYS
(Session Based on Submission of Research Abstracts.)
W. R. Opie and J. W. Poynter, Chairmen

Growth of Pearlite: L. S. Darken, R. M. Fisher, and J. M. Galligan, United States Steel Corp.

Adoption of the postulate of local equilibrium during the growth of pearlite from austenite leads immediately to the conclusion that, for a binary system, three phase (ferrite, cementite, austenite) contact cannot occur during growth. This leads to a model involving an advancing austenite-ferrite interface with cementite lamellae growing slightly behind – that is, the cementite lamellae are separated from the austenite by ferrite. Electron microscopic examination of partially transformed specimens of eutectoid carbon and low-alloy steels supports this model. The thickness of the ferrite zone between the austenite and cementite is about one-tenth the interlamellar spacing and is not readily observed in the light microscope – thus accounting for the failure of early workers to observe this phenomenon. The observed thickness of the ferrite zone is in good agreement with that computed from the observed growth rate and the diffusivity of carbon in ferrite. The small size of this ferrite zone and the relative flatness of the ferrite-austenite interface suggest a very high diffusivity of carbon in this interface.

Extension of the postulate of local equilibrium and of the above-mentioned model to low alloy steels leads to a qualitative explanation of the general retarding effect of alloys on the growth rate, in terms of the rather complex boundary conditions of the ferrite zone. The slight accelerating effect of cobalt is not inconsistent with this picture.

Effect of Applied Tensile Stress on Phase Transformations in Steel: L. F. Porter, United States Steel Corp., and P. C. Rosenthal, University of Wisconsin.

Using a specially designed apparatus capable of making simultaneous measurements of the electrical resistance and the extension of a wire specimen during rapid quenching or isothermal transformation, the transformations characteristics of a eutectoid steel have been studied under dead-weight tensile loading. Data obtained on transformation to pearlite, bainite, and martensite indicate that there is a threshold stress above which transformation is accelerated. When transforming under load, extensive plastic deformation is noted coincident with transformation. There also appears to be a threshold stress associated with the plastic deformation. In the case of transformation to pearlite and bainite, increased rates of transformation occur at the same threshold stress as the plastic deformation. For instance a 2000 psi threshold is obtained for pearlite transformed at ~688° C and an 8000 psi threshold for bainite transformed at 260° C. On transformation to martensite gross plastic deformation occurs at very low stress (1000 psi) while the M_s temperature is not raised until stresses on the order of 30,000 psi are reached.

To account for increased transformation rates and plastic extension having the same threshold during transformation of pearlite and bainite under load, it is proposed that dislocations piled up at grain boundaries and other barriers produce stress fields which result in increased rates of nucleation. Moreover, when the nucleus loses coherency with the parent austenite, the advancing interface acts as a sink for the piled up dislocations and thus, coincident with

the transformation, plastic deformation is observed. According to this picture, the threshold stress is the stress necessary to move free dislocations out from their sources to produce the piled up arrays. The difference in the behavior of the martensite transformation under load can be explained on the basis of the differences between the mechanism of formation of martensite and that of pearlite and bainite.

Nature and Kinetics of Precipitation in a 16 Per Cent Vanadium, 2.5 Per Cent Aluminum-Titanium Alloy: E. L. Harmon, Electro Metallurgical Co., Div. of Union Carbide Corp., and A. R. Troiano, Case Institute of Technology.

X-ray diffraction studies and dilatometric analysis disclosed that the presence of aluminum in the Mallory-Sharon 16 pct V, 2.5 pct Al-Ti alloy altered the transformation characteristics significantly compared with those of binary titanium-vanadium alloys. The beginning of formation of the transition phase, omega, was retarded and the temperature range in which alpha is the first decomposition product was lowered. These effects occurred for solution treatment in the beta field (1530°F) but were more pronounced for solution treatment in the alpha-beta field (1370°F). In each case the transformation kinetics were essentially the same for direct quenching to the reaction temperature and for quenching to room temperature and subsequent aging.

A new stage in the decomposition of the beta phase was observed at low aging temperatures, 500°F and below. At these temperatures formation of the omega phase was preceded by what appeared to be segregation into vanadium-rich and vanadium-poor regions retaining the body-centered cubic structure of the matrix. X-ray diffraction revealed this structure in patterns taken immediately after the aging treatments. After a time lapse of a few days at room temperature, however, the structure was no longer evident, but a faint trace of omega had appeared. Essentially similar low temperature aging behavior was later observed in a 20 pct V-Ti binary alloy.

It seems likely that this tendency toward segregation within the beta phase will occur under appropriate conditions in several other titanium alloy systems. The inflection in the $\beta/\alpha+\beta$ boundary of the titanium-chromium equilibrium diagram, as determined by the McQuillans, may be a manifestation of this tendency.

Diffusion of Heat and Mass in Growth of Precipitates from Supersaturated Solutions: C. M. Adams, Jr., Massachusetts Institute of Technology.

A mathematical analysis of combined heat and mass flow governing growth behavior of spherical, cylindrical, or plate-shaped particles, immediately after precipitation from supersaturated solid or liquid solutions, is presented, and some numerical examples are discussed. The analysis is based upon solutions to the partial differential equation of heat (or mass) flow which satisfy conditions prevailing at a moving plane, cylindrical or spherical phase boundary. The simplifying assumptions of constant mass and thermal diffusivity are made and the equations pertain to early stages of growth in which the regions of influence of neighboring particles do not overlap. The latter assumption is shown to be valid up to over 50 pct transformation under certain conditions of severe supersaturation.

The temperature and composition of the first material to precipitate are shown to depend partly upon the degree of supersaturation and are expressible in terms of the ratio of mass to thermal diffusivity. In certain cases, the amount of supercooling required to engender an effectively diffusionless reaction can be predicted. The relative rate-controlling importance of heat and mass flow in various types of reactions is assessed quantitatively. Specific examples discussed include: (a) solidification of solid solutions, (b) precipitation from solid and liquid solutions in which the composition of the precipitate is greatly different from that of the parent solution, and (c) precipitation of one solid solution from another in which composition differences are not large.

Abnormal Grain Growth in High-Purity, Extruded Magnesium: F. D. Rosenthal and G. J. Mills, Jet Propulsion Laboratory, California Institute of Technology.

Abnormal and normal grain growth was studied in the temperature range 300 to 500°C. Normal growth is preceded by a period of incubation during which no appreciable increase in grain size is evident. This incubation time rapidly decreases with increasing temperature. These observations are believed to result from the concentration of impurity atoms in the grain boundaries and their subsequent diffusion prior to and during boundary migration at elevated temperatures. Abnormal growth is recognized as a large and abrupt increase in growth rate accompanied by the appearance and continued growth of large multi-sided grains at the expense of the smaller and slower growing normal matrix grains. This high growth rate gradually decreases by matrix grain consumption and impingement and finally evolves into a normal process. This is particularly evident at the highest temperature where the normal grains are entirely consumed prior to the shortest annealing time and consequently only normal growth and its correspondingly slower rate are observed. Both the normal and abnormal growth exponents are less than the theoretical. These deviations are attributed to impurity and abnormal grain impingement effects, the former restricting the exponent to a low level and the latter controlling its progressive decrease with increasing temperature. The influence of preferred orientation on the initiation of abnormal grains is believed to emanate from the high mobility of the limited number of grains with orientations sufficiently removed from the ideal to have a high interfacial energy relative to the matrix.

A Contribution to the Phase Diagram of Silver-Copper-Cadmium: K. M. Weigert, Curtiss-Wright Corp.

Early investigations of the phase diagram Ag-Cu-Cd limited themselves to the vicinity of the binary systems. Therefore, some years ago after having investigated the ternary Ag-Cu-Zn system the author started an investigation of the Ag-Cu-Cd system with additions of zinc. The purpose was mainly to correlate the physical properties of these alloys with the joining mechanism. The publication was postponed since it became known that a more fundamental study of the Ag-Cu-Cd system was started at the Max Planck Institute in Stuttgart by E. Gebhardt and G. Petzow (Z.f.Metallkunde 47 [1956] p. 401 and 751). In their publication, the authors mentioned a paper by Tomo-o Sato and Hideo Kaneko (Nippon Kinzoku Gakkai-shi 6 [1942] p. 76) dealing with the same subject and allegedly being in good agreement with their own investigations. Going over the paper of Sato and Kaneko serious discrepancies were noticed and it seemed to be of interest to redraw all diagrams to the same scale and complete the same significant sections. Several horizontal sections were considered to be of interest and a 15 pct copper vertical section was chosen as being typical for the low flowing silver solders. In the paper of Sato and Kaneko the eutectic silver-copper field is relatively narrow. Copper is in equilibrium with the Ag-Cd beta phase and the gamma phase and also with the Cu-Cd beta phase over a large range. The 15 pct copper vertical section contains the gamma phase at 40 to 50 pct silver.

In the paper of Gebhardt and Petzow the Ag-Cu eutectic field extends towards the end of the Ag-Cd alpha field. The copper, silver, and silver-cadmium beta phase equilibrium dominates the inside of the ternary diagram. In the 15 pct copper section copper, silver, and the silver-copper cadmium beta phase are the constituents of the 40 to 50 pct silver alloys. Neither the copper cadmium beta nor the gamma phase enters these compositions. The author accepts the paper of Gebhardt and Petzow with some reservations, based on experimental evidence of Cu-Cd beta phase formation in the 15 pct copper and 40-50 pct silver range. This concept is in agreement with the physical properties of the alloys and the interface reaction mechanism. The obvious discrepancies cannot be explained by different methods of procedures. Further investigations are needed in order to come to a final conclusion.

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Heat Treatment, Transformation Reactions, and Mechanical Properties of Some High-Strength Zirconium-Base Alloys: H. A. Robinson, J. F. Doig, M. W. Mote, and P. D. Frost, Battelle Memorial Institute.

Zirconium alpha-beta alloys were found to respond to solution and aging heat treatments in a manner analogous to titanium alpha-beta alloys. A zirconium-5 wt pct molybdenum-2 wt pct tin alloy was heat treated to a 168,500 psi tensile strength and a 153,500 psi yield strength, with 11.5 pct elongation in 1 inch. In addition, a zirconium-5 wt pct niobium-2 wt pct tin alloy was heat treated to a 190,500 psi tensile and a 178,900 psi yield strength, with 2 pct elongation.

Age-hardening studies supplemented by X-ray diffraction were made for several alloys in addition to those noted above. For alloys sufficiently beta stabilized to retain beta to room temperature the aging transformations may be represented as follows:

$$\beta \rightarrow \omega + \beta_Y \rightarrow \alpha + \beta_Y$$

The omega phase in these zirconium alloys appeared to be non-cubic in contrast to omega in titanium alloys which has been found to be cubic. The aging transformations of alloys with low beta stabilizer content that transformed to alpha prime when quenched may be represented by the following reaction equation:

$$\alpha' \rightarrow \alpha + \beta_Y$$

This aging reaction is likewise found to occur in titanium alloys with relatively low beta stabilizer contents.

Preliminary elevated-temperature properties were very good. The zirconium-5 wt pct molybdenum-2 wt pct tin alloy solution treated at 1525° F and aged 8 hours at 1000° F was evaluated for tensile strength and 100 hour rupture life at 850° F. The tensile strength, yield strength, and elongation were 111,000 psi, 84,500 psi and 12 pct, respectively. The 100 hour rupture strength was about 95,000 psi.

Solid Solubility of Carbon in Copper-Nickel Alloys: M. E. Nicholson, University of Minnesota.

In some ternary systems involving two transition metals, the solid solubility of the third element drops abruptly to a negligible value at a composition of the transition binary system corresponding to a complete filling of the "3rd" quantum levels. Such a decrease in the solid solubility of hydrogen occurs in the palladium-silver system at about 60 pct silver. In the copper-nickel system, high nickel alloys are embrittled by the precipitation of graphite from solid solution. The embrittling effect disappears when copper exceeds 40 or 50 pct. This is interpreted as indicating that the solid solubility of carbon in copper-nickel alloys approaches zero at this composition.

In order to obtain information that would aid in establishing whether or not any "3d" electron-solute element interaction exists, the solid solubility of carbon in copper-nickel alloys was investigated in greater detail. A series of copper-nickel alloys was saturated with respect to graphite by carburizing in an atmosphere of carbon monoxide in the presence of finely powdered graphite at 1000° C. In the low nickel region the solubility of carbon increased from virtually zero at 0 pct nickel in a parabolic fashion until the maximum solubility of 0.16 pct carbon was reached at about 70 pct nickel. It was found that the solid solubility of carbon remained essentially constant for alloys containing more than about 70 pct nickel.

The solubility of carbon in solid copper-nickel alloys differs considerably from the solubility of carbon in liquid copper-nickel alloys. In the low-nickel region a parabolic relation exists similar to the relation which exists in the solid alloys. In the high-nickel region, above 70 pct nickel, the solubility varies as a linear extension of the parabolic curve. The solid solubility of carbon in copper-nickel alloys does not appear to be controlled significantly by the "3d" electronic structure of the alloys.

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Solubility of Hydrogen in the 50 Weight Per Cent Uranium-Zirconium Alloy: E. A. Gulbransen, K. F. Andrew, and R. J. Ruka, Westinghouse Electric Corp.

The reaction of hydrogen with the epsilon phase of the 50 wt pct uranium-zirconium alloy is studied using: (1) a sensitive vacuum microbalance apparatus to prepare the alloys, (2) a sensitive McLeod gauge to measure the dissociation pressures, and (3) X-ray diffraction analyses to determine the phases present in the alloy. Although the reaction of hydrogen with the alloy is very rapid at 100° C for oxide-free surfaces, homogenization is very slow. Hydrogen alloys are prepared in the composition range of $U_{0.78}Zr_{0.12}H_{0.40}$ to $U_{0.78}Zr_{0.75}H_{0.121}$ and the dissociation pressure measurements determined in the temperature range of 400° to 600° C.

Due to the slow processes of homogenization, the hydride $ZrH_{1.7}$ is not readily precipitated below 400° C. On heating to 525° C and cooling, the hydride is readily formed for compositions of $U_{0.78}Zr_{0.19}H_{0.249}$ and higher. For low-hydrogen compositions, the hydride is not found in the X-ray diffraction patterns on heating these compositions to 525° C and cooling. It is suggested that small hydride nuclei are formed that are not observable by X-ray diffraction methods. Due to a slow rate of metallic diffusion, these nuclei cannot grow. The solubility of hydrogen in the alloy is determined to be approximately 9.0 atom pct at 500° C. This is a smaller value than that found for pure zirconium. However, the heat of solution of hydride is −8,500 ± 1,500 calories per gram-atom and compares with a value of −8,600 calories per gram-atom found for zirconium. A transformation of the epsilon to gamma phase of the alloy is found near 550° C.

Thermal Fatigue of Ductile Materials—I. Effect of Test Conditions on the Thermal Fatigue Life of S-816 and Inconel 550: F. J. Claus, Lewis Flight Propulsion Laboratory, and J. W. Freeman, University of Michigan.

An experimental study was made of the effect of the following factors on the life of ductile alloys under high-temperature thermal fatigue conditions: (1) the maximum cycle temperature; (2) the temperature difference of cycling; (3) the cyclic time of exposure at the maximum cycle temperature; and, (4) the cyclic plastic strain suffered by the material in order to absorb the thermal strains. Tensile specimens of S-816 and Inconel 550 were alternately heated and cooled while constrained in a manner that prevented their free axial expansion and contraction, and the number of cycles to failure was determined. Hardness measurements and microstructural studies were made.

Results indicated that the maximum cycle temperature had more effect than the temperature difference on the number of cycles to failure. Increasing the cyclic time of exposure at the maximum temperature improved the thermal fatigue life at high maximum cycle temperatures, whereas the same increase in exposure time at low maximum cycle temperatures decreased the number of cycles to failure. The number of cycles to failure was found to depend upon temperature and time effects in addition to the thermal strains absorbed by the materials.

Thermal Fatigue of Ductile Materials—II. Effect of Cyclic Thermal Stressing on the Stress-Rupture Life and Ductility of S-816 and Inconel 550: F. J. Claus, Lewis Flight Propulsion Laboratory, and J. W. Freeman, University of Michigan.

A study was made of the changes in the stress-rupture life, ductility, hardness, and microstructure of S-816 and Inconel 550 specimens that had been exposed to varying amounts and conditions of thermal fatigue, in which the number of cycles was insufficient to cause fracture by thermal fatigue alone.

Exposure to thermal fatigue conditions strengthened one alloy and weakened the other. Under the most damaging conditions

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studied, Inconel 550 lost 98 pct of its original stress-rupture life as a result of prior thermal fatigue even though the number of cycles was only one-half of that required for failure by thermal fatigue alone. Under the same conditions, the stress-rupture life of S-816 was increased about 50 pct. Opposite behavior was noted for the reverse order of testing. Thus, when specimens were first exposed to stress-rupture conditions and then run to failure in thermal fatigue, the thermal fatigue life of S-816 was sharply reduced whereas that of Inconel showed a slight increase.

Existing theories on mechanical fatigue and creep-rupture have been extended to cover thermal fatigue behavior. The differences in the behaviors of the two alloys studied has been explained by separating the thermal fatigue process into the following two stages: (1) a stage of strain- and/or precipitation-hardening during which the ductility is reduced and the strength is increased, and (2) a stage of the destruction of the cohesive bonds and the development and propagation of cracks. Structural changes are shown to be an important part of thermal fatigue behavior.

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Symposiums

Steelmaking Practices
Continuous Steelmaking

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TUESDAY, NOVEMBER 5

9:00 am to 12:00 m, Exhibit Hall

SESSION I—RECENT DEVELOPMENTS IN STEELMAKING PRACTICES
H. B. Emerick and Pierre Coheur, Chairmen

Observations Regarding Properties and Performance of Continuously Cast Low Carbon Steel Products: R. N. Edmonson, L. Mair, and M. Tenenbaum, Inland Steel Co.

Some operating aspects involved in the continuous casting of some types of low carbon steels were described in an earlier paper. Cast sections were rolled in the conventional manner into standard commodities. The rolled products were inspected, tested, and then applied in representative jobs where the section allowed. The inherent hot-working characteristics observed in rolling the cast sections appeared entirely acceptable for commercial processing. There was considerable variation in rim thickness in rimming type steels. Much of this variation resulted from intentional variations in operating conditions. The narrow rim thickness usually resulted in poor surface quality and low yield. Those rim steel sheets which passed inspection could be drawn normally well in moderate cold pressing operations.

Low-carbon types of steel rolled readily into sheet products with acceptable surface quality. These products performed well in all cold-pressing jobs. Fully aluminum killed steels generally had poor surface quality. A limited number of sheets of this type that passed inspection performed well in cold pressing and spinning jobs.

Continuously cast low carbon high sulfur steels hot rolled well into merchant bar sections which were then cold drawn and used successfully for machining applications.

The measured properties of all the rolled products were considered normal when allowances were made for residual elements.

Vacuum Arc Melting: F. W. Johnson, Westinghouse Electric Corp.

Arc melting in chilled crucibles is becoming increasingly important as a method of producing sound, high-quality products without atmospheric or crucible contamination. Three variations of arc melting are: (1) with inert atmospheres and non-consumable electrodes, (2) with inert atmospheres and consumable electrodes, and (3) with consumable electrodes in vacuum. Method (3) is superior for most applications and is expected to have the fastest development and growth. Of major importance in the development of vacuum arc melting is the collection of new, fundamental information on the behavior of high current arcs at reduced pressures. Work in this new field is proceeding vigorously, and many worthwhile results have been obtained.

From consideration of the present capabilities and limitations of consumable electrode vacuum arc melting it is expected: (1) that the method will be applied to an increasing number of alloys, (2) that new alloys having superior properties will be developed to take particular advantage of the capabilities of the process, and (3) that the process will become increasingly versatile and economical, permitting further increases in the number and variety of materials that will be vacuum arc melted.

Nitrogen in Steels from Different Steelmaking Processes: K. G. Speith and H. vom Ende, Mannesmann-Huttenwerke A.G., Duisburg, Germany

Nitrogen dissolved in a steel melt depends on the charged materials and the steelmaking process. Sources of nitrogen in the open-hearth and electric furnaces are discussed. Open-hearth melts do not pick up nitrogen from the gas phase. Normal nitrogen contents of open-hearth and electric steels are shown. Nitrogen absorption in air-blown steels is discussed. This absorption is dependent upon the quantity of nitrogen blown through the bath, time of blow, and

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temperature. The influence of oxygen enrichment, height of bath, and age of converter are discussed. The obtainable nitrogen contents in the bottom-blown vessel are compared and the most favorable working methods are described.

Very low-nitrogen contents are obtainable in bottom-blown converters using oxygen-steam and oxygen-CO_2 mixtures. The course of the reactions are described as are the process variables. The processes involving the blowing of pure oxygen on the surface of the metal are described (L-D, Kalling-Drum, Oberhausen Rotor). Refining cycles for the blowing of iron with high and low phosphorus contents using pure oxygen are given. Obtainable nitrogen contents in steels produced by all commercial steelmaking processes are summarized. The influence of nitrogen on the behavior of killed and rimming steels is mentioned.

Observations of the Russian Steel Industry: N. J. Grant, Massachusetts Institute of Technology.

During June and July of 1957 Professors J. Chipman and N. J. Grant of the Massachusetts Institute of Technology visited Russia. While there they saw a number of steel plants and research institutes, and discussed the higher educational system for scientists and engineers in the U.S.S.R. An informal commentary on what was observed and impressions derived thereof will be presented.

TUESDAY, NOVEMBER 5

2:00 to 5:00 pm, Exhibit Hall

SESSION II—CONTINUOUS STEELMAKING
K. L. Fetters, Chairman

Some Thoughts on Continuous Steelmaking and Its Development: J. F. Elliott, Massachusetts Institute of Technology.

Discussion by panel of well-known metallurgists.

Marc Allard, Institut de Recherches de la Siderurgie, St. Germain-en-Laye, France
C. R. Taylor, Armco Steel Corp.
M. Tenenbaum, Inland Steel Co.
D. L. McBride, United States Steel Corp.

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Fundamentals Of Scale Model Experiments

Pilot plant studies can be potent tools toward understanding complex metallurgical processes. Since industries grow more economic with size, pilot plants are a necessary step in both the design and economics of process development.

by W. O. Philbrook

NEITHER capital investment nor operating cost of a furnace or mill increases in direct proportion to its size, so large plants with huge producing units can operate at lower cost per ton of product than smaller installations. The need for bigness places a severe hurdle in the path of developing and launching a new process. New processes are not born big, but grow through laboratory and pilot plant stages. A considerable extrapolation is necessary, not only to design large-scale producing units, but also to predict whether the costs can be competitive with existing methods for accomplishing the same ultimate results.

It is evident that there is a great incentive for the process metallurgist to use reduced scale models or pilot plant facilities to study metallurgical processes, provided that information learned in this way can safely be extrapolated up to full-scale operation. One of the strongest justifications, in fact, is that some metallurgical processes are so complex that almost the only hope of understanding them lies in breaking them down into sub-processes that can be studied independently under laboratory control. Indeed, some of our laboratory tests, such as the determination of the reducibility of an ore or the permeability of a bed of charge materials, are attempts to isolate a portion of the process for controlled study. Sometimes this relation of the test to the process is not clearly recognized, similarity criteria are not considered, and the results of the test are likely to be misinterpreted. It is, therefore, worth while to understand the guiding principles of model study so that the information obtained in the laboratory or pilot plant may be used intelligently to synthesize a picture of the over-all process.

The province of the scale model and the pilot plant is the study of flow or transfer processes in which fluid flow, heat or mass transfer by one or more of several possible mechanisms, or chemical kinetics, may play significant roles.

W. O. PHILBROOK is Professor of Metallurgical Engineering, Carnegie Institute of Technology, Pittsburgh. This paper was prepared with the cooperation of the U. S. Bureau of Mines Pyrometallurgical Laboratory, Pittsburgh, and was presented at the AIME Annual Meeting, New Orleans, February 1957.

The author takes sole responsibility for interpretations and opinions expressed.

The objective of model study

The two objectives mentioned earlier have been designated by Thring[1] as *prediction similarity* when the objective is the design and translation of new processes from the laboratory to full scale, and *diagnosis similarity* when the intention it to learn more about the laws governing existing processes. The underlying principles are the same for both, but the latter application implies that a considerable amount of experience with the behavior of the process in full scale is available. This would enable shrewder judgments to be made about several aspects of the problem of model study. To begin with, dimensional analysis is the backbone of the method, and Bridgman[2] stresses that this tool requires some sophistication about the nature of the process under study. Further, the complexity of real metallurgical processes makes it impossible to attain full similarity between scale models and commercial prototypes.[1,3] Success of the method rests entirely upon whether or not it is possible to relegate some subprocesses to a negligible role or to learn to correct for them by calculation based on systematic investigation. A considerable amount of judgment and

Table I. Nomenclature of terms used

A = area, sq ft
c_p = specific heat, Btu per (lb) (F)
d = diameter of a particle, ft
D_v = mass diffusion coefficient, sq ft per hr
g = local acceleration of gravity, ft per sq sec
g_c = dimensional constant, 32.17 $(lb_{mass})(ft)$ per $(lb_{force})(sec)^2$
h = local individual coefficient of heat trasfer, Btu per (hr) (ft) (F)
J_H = dimensional constant, 778 (ft) (lb_{force}) per Btu
k = thermal conductivity, Btu per (hr) (ft) (F)
L = linear dimension characteristic of size of a given system, ft
q = rate of heat transfer, Btu per hr
t = temperature, °F
V = velocity, ft per sec
V_s = superficial velocity calculated for empty cross-sectional area of duct, sq ft
α = thermal diffusivity, sq ft per hr, $= k/\rho c_p$
ϵ = void fraction of bed, dimensionless
θ_R = retention time, hr
μ = dynamic viscosity, lb_{mass} per (ft) (hr)
ν = kinematic viscosity, sq ft per hr
ρ = density, lb_{mass} per cu ft
σ = surface tension, lb_{force} per ft

caution must be used in drawing conclusions from reduced scale experiments when anything more complex than simple flow is involved.

Similarity conditions

Model laws are simply statements of conditions under which similarity prevails for both the model and the prototype with respect to certain qualities. What constitutes similarity?

The first type of similarity, which is so fundamental that it often is not specified explicitly, is geometric similarity. The conditions for it are a three-dimensional equivalent of photographic enlargement or reduction; i.e., identity of shape, equality of corresponding angles or arcs, and a constant proportionality or *scale factor* relating corresponding linear dimensions. Geometric equivalence is required of all isotropic processes, but it may be possible to relax this requirement for non-isotropic systems.[1] For example, in a shaft furnace operating under steady flow it may be possible to neglect or correct for flow in the radial direction, so that the process need be modelled only for similarity in the axial direction; or perhaps different scale moduli might be appropriate for axial and radial dimensions.

Just as geometric similarity requires a constant proportionality ratio for linear dimensions, other kinds of similarity require proportionality of other qualities. Kinematic similarity requires that velocities and velocity gradients be in the same ratio at equivalent positions in similar systems, and dynamic similarity requires that the various transfer processes, transfer of momentum, mass, and heat, be in constant ratio. The conditions for such similarities are usually reduced to certain dimensionless parameters. Often the final objective of a model study is not simply to establish conditions of complete similarity for one mode of operation but rather to learn the natural laws under which the process operates as revealed by a functional relation among some of the dimensionless parameters. Here dimensional analysis is of assistance.

Dimensional analysis

In scientific usage—the centimeter-gram-second system—the number of independently defined units is held to a minimum by the selection of secondary units that are related to the primary ones by proportionality constants of unity; the dyne and erg are examples. There is, however, no *absolute* basis for such limitation, and many arbitrarily defined units are found in common use—arbitrary units of force, pressure, heat, electrical energy, power, etc. In general, when an independent primary unit is defined for a quantity which could also be expressed in terms of other primary units, then there is a corresponding proportionality constant that interrelates the magnitudes of the independently defined units of measurement. Such constants have both numerical value and dimensions and are known as *dimensional constants*. Important examples are the one expressing the definitional relation between the pound of force and the other primary units of the engineering system, $g_c = 32.17$ (lb_{mass}) (ft)/(lb_{force}) $(sec)^2$, and the mechanical equivalent of heat, $J_e = 778$ (ft) (lb_{force})/Btu. The dimensional constants enter into equations expressing natural laws in which primary units occur that are not interrelated by factors of unity.

The Π *Theorem* of dimensional analysis states[2] that all of the significant variables and dimensional constants that are necessary to describe a real process can be arranged into groups in which the dimensions of the individual terms cancel out. This is possible because all dimensions are products of powers of the primary units, and products or quotients of these terms taken to appropriate exponents can be arranged so that the algebraic sum of the exponents for each primary unit vanishes. Usually the number of such dimensionless groups is equal to the number of independent variables and dimensional constants minus the number of primary units, but there are exceptions to this rule under certain mathematical conditions. A consequence of the Π Theorem is that the natural laws describing a process are independent of the system of units employed. It is necessary only that all quantities within a dimensionless group be expressed in consistent units.

The natural laws that describe the functional relation among the variables of any process can be expressed as some mathematical function of its dimensionless parameters. This function may be simple or complex, algebraic or transcendental. Its form must be discovered by experiment. Dimensional analysis can not find the solution but can assist by showing how the variables may be arranged into dimensionless groups. This information can greatly simplify the experimental effort needed to establish a correlation law, as it is not necessary to vary each factor individually but only the groups as a whole. These principles will be clarified by some examples from common fluid-flow and heat-transfer applications.

One important consequence of dimensional analysis for application to model laws is that the dimensional groups are criteria of similarity. For example, in the steady flow of fluid through two geometrically similar systems, kinematic similarity requires that the velocity and velocity gradients be in the same proportions in the two systems at corresponding locations, and dynamic similarity demands that the ratio of viscous to inertial forces be the same for both systems. These conditions are satisfied if $L_1V_1\rho_1/\mu_1 = L_2V_2\rho_2/\mu_2$. (Symbols are defined in Table 1.) The quantity $LV\rho/\mu$ will be recognized as the dimensionless parameter called the Reynolds Number, N_{Re}, that characterizes the state of motion of a fluid in a given system. It will be recalled that the friction factor, used to calulate pressure drop in the flow of fluid through a duct, is the same for equal values of the Reynolds Number in geometrically similar systems (same shape and roughness).

Applications to heat transfer

An example of the functional relation among the dimensionless groups for a natural process may be taken from the familiar field of heat transfer. The rate of convective heat transfer between a fluid and a surface is commonly taken as proportional to the surface area and to the temperature difference between the bulk of the fluid and the surface:

$$q = h A (t_i - t_s)$$

The proportionality constant h is called the *local individual coefficient of heat transfer*.

It is desired to predict h as a function of the geometry of the system, the flow conditions, the properties of the fluid, and any other relevant factors. It is found that three dimensionless groups are sufficient. Under forced convection, the Reynolds Number describes the state of motion, just as it does for fluid flow; and the Prandtl Number, $N_{Pr} = c_p\mu/k$, ac-

counts for significant properties of the fluid. The heat transfer coefficient must be included within the third dimensionless group, which may be the Nusselt Number, $N_{Nu} = hL/k$. (An alternate choice, the Stanton Number, $N_{St} = h/V\rho c_p$, is obtained by dividing N_{Nu} by the product $N_{Re} \cdot N_{Pr}$ and yields no new information.) The problem then becomes one of finding the functional relation among N_{Nu} (or N_{St}), N_{Re} and N_{Pr} for a given geometrical arrangement.

For turbulent flow conditions within restricted ranges of Reynolds Number, the functional relation can commonly be represented by an equation of the form:

$$\left(\frac{h\,L}{k}\right) = C\left(\frac{LV\rho}{\mu}\right)^{m}\left(\frac{c_p\mu}{k}\right)^{n}$$

Here, the coefficient C and the exponents m and n depend upon the geometry of the system and the range of values of N_{Re}, but one relation will correlate data for a variety of gases and liquids.* The reason for the multiplicity of empirical correlation equations in the heat transfer literature[2] is that different relations apply for each shape of surface and its orientation to the stream, as well as for limited ranges of flow conditions in natural and forced convection. Each of these relations must be established by experiment, but in this field it is well recognized that laboratory results may accurately predict the behavior of commercial apparatus where similarity prevails.

* It is noteworthy that analogous correlation equations are found for the transfer of heat, mass, and momentum (friction loss) in geometrically similar flow systems.[3] Under natural convection a different group replaces the Reynolds Number in correlations for both heat and mass flow.

One of the important applications of dimensionless groups as criteria of similarity in model studies is to show how scale factors and property values can and must be adjusted to maintain similarity between model and original. Here it will be convenient to use $N_{Re} = LV/\nu$, where $\nu = \mu/\rho$ is called the kinematic viscosity. If one wants to build a flow model to 1/10 scale in linear dimensions and to use the same fluid, then the velocity must be ten times as great in the model to give $L_1V_1/\nu_1 = L_2V_2/\nu_2$ and hence dynamic similarity for both model and full-scale apparatus. High velocities are sometimes inconvenient or difficult to attain, and another alternative is possible for a simple flow system. The kinematic viscosity, ν, is 0.0435 sq ft per hr for water at 60°F and 0.568 sq ft per hr for air at the same temperature, a ratio of about 1:13. It can be seen that dynamic similarity is possible at equal velocities if the model is made to 1/13 linear scale and water is substituted for air. The kinematic viscosity of gases increases with temperature, and for air it is higher at 2500°F than at 60°F by a factor of about 20. A cold air model at 1/20 scale in linear dimensions could be used to simulate flow of air at 2500°F using the same velocity in the model as in the full-scale process. This principle of adjusting both fluid properties and scale moduli to maintain similarity in the Reynolds criterion has been rather widely used in flow models for gaining information about movement of gases through ports and furnaces.

Problems of real situations

Thus far only one dimensionless group has been considered, but quite often more than one is involved in attaining full similarity between model and prototype. Gravitational forces are assumed negligible in fluids in steady flow along a duct, but they become important in situations where wave motion is involved, as in ships moving through waves in deep water or slag and metal in motion in a converter. The criterion for similarity in the ratio of kinetic to potential energy is the Froude Number $N_{Fr} = V^2/Lg$. It is obviously impossible to attain similarity for both the Reynolds and Froude number simultaneously with the same fluid with any change in linear scale, because if LV is held constant, V^2/L can not be constant also unless L and V remain unchanged. It is not likely in practice that a suitable choice of fluid can be made so that μ/ρ can be altered to permit similarity for both N_{Re} and N_{Fr}. The dilemma of modelling to meet more than one criterion of similarity arises even for relatively simple systems.

An experimental converter used in pilot plant studies by the U. S. Bureau of Mines.

The partial solution for such problems lies in some knowledge of the behavior of the systems. It is known from a considerable body of experience in the flow of fluids that the Reynolds Number becomes relatively unimportant once fully developed turbulent flow (high values of N_{Re}) has been attained. It is, therefore, a reasonable presumption but one requiring verification, that the Reynolds criterion might have only minor or negligible influence under certain circumstances where highly turbulent flow could be expected. In model experiments designed to simulate the motion of metal and slag in steelmaking converters, useful results have been obtained by modelling to obtain similarity with respect to Froude Numbers rather than Reynolds Numbers for slag and metal. In a similar fashion, the necessity of considering similarity of Mach Number rather than Reynolds Number is recognized in aerodynamic studies at sonic and supersonic velocities. In processes where surface or interfacial tensions would play a major role, as in the emulsification of slag and metal, Weber Numbers, $N_{We} =$

$L\rho V^2/\sigma g_c$, for one or more phases would in all probability be important.

Movement of solid particles

The pattern of movement of individual solid particles in a stream or mechanically disturbed bed, including mixing, unmixing, and segregation because of size, shape and specific gravity differences, can be of considerable importance because of the influence of the particle distribution on fluid flow, heat transfer, and chemical reactions that will transpire within the bed so formed. An excellent example is the distribution of charge materials on the stock line of a blast furnace from the skip car through the bell and hopper arrangement. Several model studies have been made and good agreement has been shown between model and actual charge distribution in a large blast furnace. The forces at work are gravity and friction, so it is desirable to use the same materials in model and full scale for similarity as to shape factors and coefficients of friction. Traustel[4] has stated the model law for similarity of seiving characteristics with size reduction; it may be worded in another way as follows: If the screen size distribution of the natural-size material is plotted in the usual fashion as per cent retained on seive vs the logarithm of the screen aperature, then a lot which is of reduced particle size but geometricaly similar should have a size distribution curve identical in shape with that of the natural sample but displaced along the horizontal (logarithmic) size axis by a distance equal to the log of the linear scale factor. For problems involving the fall of particles through air or liquids, it will be necessary for the experimenter to consider whether the laws of settling and classification or elutriation introduce significant similarity requirements in addition to simple geometry.

Fluid flow models

The Reynolds criterion and related aspects of flow models have already been discussed. A great many studies of flow patterns in various portions of open hearth furnaces of several designs have been made in England, France and Germany during the past dozen years. For locations where essentially one- or two-dimensional flow could be assumed, slice models made of transparent plates or water tables have been used to discover flow patterns and points of excessive impingement or erosion of walls by gas streams, etc. Three-dimensional transparent plastic models have also been made. The flow patterns indicated by the models have been checked in operating furnaces by means of smudge blocks held in critical points to produce a smoke plume to trace the flow lines, pitometer probes, etc.

The flow of fluids through packed columns, and more recently through fluidized beds, has been studied intensively, and a variety of correlation procedures have been advanced for relating the flow rate and pressure drop, or bed permeability, to characteristics of the charge. For uniform beds, several methods of correlation are in reasonably good agreement when translated into common form, except that there appears to be a range dependent on particle shape for highly turbulent flow[3]. When it is considered that true geometric similarity would not be obtained upon dumping and refilling a column with the identical charge in random packing, some statistical variation must be expected at best. Unfortunately, however, methods of predicting variations with particle shape leave much to be desired, and there is great need for systematic work on flow in segregated and stratified beds such as are found in blast furnaces.

Traustel[4] has stated that similarity with respect to over-all permeability of a bed of solids can be accomplished even though Reynolds similarity may not be obeyed down to the smallest details of flow past individual particles. He believes that similarity of flow in the smallest detail is not significant in scaling combustion, gasification, and smelting processes using coke and ore. It does not seem safe to assume, however, that the gross segregation known to prevail in blast furnaces can be ignored entirely.

Chemical reactions and hot models

The operation of a high-temperature metallurgical process on a reduced scale to obtain results that are quantitatively useful for predicting or explaining behavior in full-scale is a most difficult problem. Indeed, it is probably necessary in general to operate models in several different ways in order to be able to draw inferences that will help to construct the total picture rather than to hope for exact answers.

Damköhler[5] seems to have been the first to enunciate similarity rules for processes involving chemical reactions. He derived five conditions that are necessary for similarity between original and model for a chemical reaction vessel in which flowing gases react with each other or with the walls (and contents) to exchange matter and heat. These criteria express balances of competition between processes for the exchange of momentum, heat, and material; the dimensionless ratios must have the same values, respectively, for both the model and the original process if similarity holds true. Thring[1] has stated these criteria in non-mathematical language as follows:

1. Dynamic similarity criterion
$$\frac{\text{Inertial force per unit volume}}{\text{Viscous force per unit volume}}$$
2. First chemical criterion
$$\frac{\text{Molecules generated per sec by reaction}}{\text{Molecules removed per sec by flow}}$$
3. Second chemical criterion
$$\frac{\text{Molecules generated per sec by reaction}}{\text{Molecules removed per sec by diffusion}}$$
4. First thermodynamic criterion
$$\frac{\text{Heat generated per sec by reaction}}{\text{Heat removed per sec by flow}}$$
5. Second thermodynamic criterion
$$\frac{\text{Heat generated per sec by reaction}}{\text{Heat removed per sec by conduction etc.}}$$

Selection of criteria

The problems of modelling to all five criteria are readily apparent. If L is a characteristic dimension of the vessel in the direction of flow and V_s is the mean velocity calculated for the empty cross-section, commonly called the superficial velocity, then L/V_s is the mean retention time θ_s, for the system. It is obviously impossible to have similar retention

times and also similarity in $N_{Re} = LV\rho/\mu$ unless the fluid properties are adjusted, and this would lead to hopeless complications in a chemical reaction process. It is necessary to abandon the Reynolds criterion of similarity, but to try to keep the same type of flow, i.e., turbulent or streamlined, in both model and original and to make such corrections as may be possible from supplementary information when the results are interpreted. Another complication is that retention times for fluids and for solids may be different in counterflow or batch processes. It is necessary to analyze each individual process to decide which of the similarity criteria is the most critical one for the particular problem at hand.

An interesting application of Damköhler's principles was made by Edgeworth-Johnstone,[7] who was interested in both homogeneous and heterogeneous reactions from a chemical engineering viewpoint. He concluded that if the first and third criteria stated above are neglected (chemical reaction rate controlling rather than diffusion), then the requirements for similarity are: 1) Reaction time the same on large and small scale; 2) average temperature of reaction mixtures the same; and 3) surface heat losses through the walls of the vessel constitute the same fraction of the total heat input for both large and small scale processes.

Application to gasification of fuels

Traustel' made a detailed analysis of the application of model theory to solid fuel gasification and blast furnace smelting. Careful study of his treatment will show that the parameters that he developed are equivalent to the five similarity criteria of Damköhler cited above. Traustel's application of chemical kinetics and equilibrium considerations is quite different in form from Edgeworth-Johnstone's but it leads to the same conclusions; namely, that where several chemical reactions are involved, chemical similarity can be met only if all the corresponding temperatures, pressures, and compositions are the same for the model as for the large system.

A model electric arc furnace, used in pilot plant studies.

In considering fluid friction, heat transfer, and mass transfer between solid and gas by convective processes in a bed of particles, Traustel treated the bed as a pervious mass without regard to similarity down to the scale of the individual particle. He made use of empirical correlations of transfer coefficients versus the Reynolds number that were derived for beds of uniform spheres at fairly high turbulence, where the exponent on the Reynolds number approaches zero. He also took a correlation obtained from heat transfer experiments and applied it to mass transfer with the assumption that the Schmidt Number, ν/D_v, is equal to the Prandtl Number, $\nu/a = c_v\mu/k$. His conclusions are therefore somewhat uncertain to the extent that these assumptions are only approximations. No allowance was made for segregation within the bed nor for radial temperature or composition gradients.

Traustel's model laws for the gasification of fuel take into account the reaction of the fuel with the gas as a simple surface reaction involving no diffusion gradients within the solid. Boiled down to their essence, his conclusions were as follows: If the same fuel is used at the same temperature and pressures in both model and full-scale, then chemical similarity requires that the ratio L/dV_s should be the same for both.* This means that the ratio of retention time (L/V_s) to particle size is constant. For heat transfer similarity within the bed, L/d should be constant. The two together mean that the particle size should be reduced in the same proportion as the depth of the bed, and the superficial velocity should be the same for both model and large-scale gasifier. Similarity with respect to radial heat loss to surroundings can be accomplished by making the walls of the model the same thickness as the walls of the large unit or by the use of supplementary heating or insulation to accomplish the same result. The same conclusions were reached by Edgeworth-Johnstone for heterogeneous reactors in which the catalyst size was held in proportion with the vessel size, a situation analogous to a gasifier. No account has been taken of end losses, nor of heat storage on starting up or changing from one steady-state temperature level to another. If Reynolds number similarity is to be adhered to, the only condition under which similarity could be obtained with a model of $1/m$ size would be to use a fuel m-times as reactive.

* The dimensionless factor $\frac{\varepsilon}{1-\varepsilon}$ should be added to this ratio if there is any change in bed voidage, although Traustel does not show this term.

Application to shaft furnace smelting

In extending his analysis to the smelting of iron ores in a shaft furnace, Traustel took into account the transfer of oxygen from within the lump to the gas stream. In order to do this, however, he assumed a process that is considerably different from the real one in fine detail, and consequently his conclusions may require some modification by experimental determination. He recognized two extreme possibilities: 1) The absolute reducibility of the ore is extremely high so that the main resistance to the transfer of oxygen to the reducing gas is diffusion through a boundary film; and 2) the reducibility of the ore is extremely low so that the main resistance to reduction lies in oxygen transfer within the lump.

He considered that the practical case would lie somewhere between these extremes.

The reduction process is assumed to occur in a bed consisting of a mixture of fuel and ore in which the ore settles concurrently and at the same rate as the fuel. The model laws with respect to the size of the fuel and the superficial velocity are the same as given above. The additional factor is the size of the ore particle relative to the fuel. Traustel found that a highly reducible ore should be scaled to the same size as the fuel; that is, both should be reduced in size in proportion to the depth of the bed. The process going on inside the ore lump is of little consequence, so the same rules apply to it as to the fuel. For the poorly reducible ore where diffusion within the lump is controlling, the reduction in size should be proportional to the square root of the scale factor for ore size or bed depth. These limits must be considered provisional in view of simplifications involved in their derivation, and it would be of interest to see how well they apply in experimental furnaces and reducibility tests.

Traustel also gave thought to the limitation on bed depth because of the possible lifting and blowing out of the charge when the lifting force of the air blast at the bottom equals or exceeds the static weight of the bed. He concluded that blast furnace models 16 to 20 ft high would be practical. He recognized the limitations of such reduced models, including the fact that coke strength and dust losses could not be properly assessed as well as other restrictions already mentioned.

However, an entirely different set of conditions exists in the bosh and hearth, so the modelling problem is even more complex than this brief review might suggest.

Saunders, Butler and Tweedy[16] operated an experimental blast furnace with the main object of determining how the distribution of materials in the stock column influenced the temperature and CO_2 distribution in the stack. They aimed to attain process similarity by adjusting the blast rate to give a normal CO/CO_2 ratio in the top gas, and found that the similarity criterion was more nearly $V/\sqrt{L}$ than the V/L expected theoretically.

Reverberatory and arc furnaces

The process of flame development in reverberatory furnaces is largely a matter of diffusional mixing of the fuel and air streams, and hence it is important to achieve Reynolds similarity for these streams at critical cross-sections. If the furnace model is made geometrically similar and reduced in scale, the ratio of external surface for heat losses to combustion volume increases inversely with the linear scale modulus. Thring[1] discusses methods of getting around the difficulty by changing the geometry of the model, operating the model at reduced temperature and with colder hearth and walls, or using fuel of lower calorific value.

The problem of excessive heat losses in proportion to normal process heat evolution or requirement plagues all reduced-scale high-temperature experimentation because of the unfavorable ratio of surface to volume. This is especially evident in batch-type experiments where heat storage in refractories is far out of proportion to steady-state conduction losses. The problem can be handled reasonably well by engineering calculations when the source of heat is not intrinsic to the operation, as in arc or induction furnaces and to a reasonable extent in reverberatory furnaces and rotary kilns. On the other hand, autogenous processes like roasting and converting would require auxiliary heating or insulation or else a charge of higher than normal calorific value that would modify the metallurgy of the operation.

The problems of modelling submerged arc electrothermic furnaces have been analyzed in two recent papers that consider basically different modes of operation. For the case where conduction heat transfer through the walls is the controlling factor, Böckman[17] concluded that direct proportionality was necessary between power input and linear dimensions of the furnace, and he reported favorable comparisons between models and industrial furnaces for calcining anthracite and smelting ore. Saibel, Ling and Greene[18] analyzed the operation of submerged arc furnaces in which the radial heat loss through the walls was considered to be small compared with losses through the electrodes and the top of the charge. They developed the similarity conditions for predicting power requirements for two extremes of operation, found that complete similarity can not always be achieved, and presented some approximate methods for comparing furnaces.

Conclusions

In summary it may be said that reduced scale model and pilot plant experiments are based on the principles of similarity, which require that certain dimensionless parameters descriptive of the limiting physical and chemical processes must be the same for both model and full-size equipment. In the usual practical case, there are so many different natural processes involved, each with its own set of similarity criteria, that it is impossible to accomplish complete similarity. A careful analysis must then be made to learn which natural laws are the most critical and which may be neglected or for which a correction can be made from experience with other models. If allowance is made for the fact that models may have to be operated in several ways to produce the desired picture, and that the results should often be used as inferences rather than positive conclusions, then such studies can be potent tools toward understanding our complex and gigantic metallurgical processes.

References

[1] M. W. Thring: The Construction of Models in Which More Than One Process is Similar to the Original. *Trans.*, Institution of Chemical Engineers, 1948, vol. 26, pp. 91-97.

[2] P. W. Bridgeman: *Dimensional Analysis*. Yale University Press, New Haven, 1931.

[3] M. W. Thring: Application of Similarity Principles to Metallurgical Problems. *Research*, 1947-48, vol. 1, pp. 492-500.

[4] S. Traustel: Model Laws of Gasification and Smelting. *Iron and Coal Trades Review*, 1949, vol. 158, pp. 1167-1172, 1225-1231. This appears to be a condensed English version of a book by the same author: *Modelgesetze der Vergasung und Verhüttung*. Akademie Verlag, Berlin, 1949.

[5] William H. McAdams: *Heat Transmission*. Third Ed. McGraw-Hill Book Company, Inc., New York, 1954.

[6] E. R. G. Eckert: *Introduction to the Transfer of Heat and Mass*. Ch. 5. McGraw-Hill Book Company, Inc., New York, 1950.

[7] P. C. Carman: *Flow of Gases Through Porous Media*. Ch. 7. Academic Press, Inc., New York, 1956.

[8] G. Damköhler: section in Eucken and Jakob, *Der Chemie-Ingenieur*, Vol. III, Part 1, pp. 453-468. Akademische Verlagsgesellschaft m.b.h., Leipzig, 1937. See also, *Zeit. Elektrochem.* 1936, vol. 42, p. 846; 1937, vol. 43, pp. 1-13.

[9] R. Edgeworth-Johnstone: The Transference of Chemical Processes from Small to Large-Scale Operation. *Trans.*, Institution of Chemical Engineers, 1939, vol. 17, pp. 129-136.

[10] H. L. Saunders, G. B. Butler, and J. M. Tweedy: Investigations on an Experimental Blast-Furnace, *Journal*, Iron and Steel Institute, 1949, vol. 163, pp. 173-206.

[11] O. C. Böckman: Some Experiments with Scale Models of Electrothermic Furnaces. *Journal* Electrochemical Society, 1954, vol. 101, pp. 493-496.

[12] Edward Saibel, F. F. Ling, and William Greene: Analysis of Power Requirements and Conditions for Similitude in Electrothermic Furnaces. Paper presented before the American Electrochemical Society, 1956; to be published.

Design of Pyrometallurgical Pilot Plants

Pilot plants cannot usually be designed to resemble large-scale operations in every respect. Excessive heat loss in comparison with industrial installations is the major problem in scaling pyrometallurgical operations.

by R. C. Buehl

THE major function of a pilot plant must first be decided so that emphasis is placed on those factors which most influence the desired results. A small pilot plant is normally more flexible and less expensive to operate than a larger one but the results will not be as close to those of industrial operations. Consequently the size of the pilot is very important, and for any process the optimum size may be greatly influenced by the factors to be investigated.

This discussion is directed toward the design of pilot plants to study entire processes. These present more design problems than pilot production units primarily intended to make material of a desired composition or shape or than models intended for the investigation of a particular phenomenon or reactions involved in a process.

Design of specific plants: electric arc melting furnaces

Small electric furnaces, both induction and arc, are very satisfactory for the melting of metals to produce alloys of a desired composition. However, the loss of readily oxidizable elements is considerably greater than for large-scale operations unless special precautions are taken, and this will usually result in a dirtier metal than that obtained from large heats. Power and electrode consumption is much greater than for industrial furnaces, but data are available which permit the calculation of the differences. Most of the author's experience with electric furnaces has been with a 3-ft diam electric arc furnace powered with 200 kva and melting up to 500 lb. In such a furnace, basic slags would not remain strongly reducing for more than 5-min after the addition of a reducing agent to the slag under normal operation. The use of tight-fitting glands around the electrode, of a tight-fitting door, and of a curtain of non-oxidizing gas in front of the door reduces oxidation of the slag to a considerable extent. However, for accurate control of reducing slags a gas-tight furnace would be desirable.

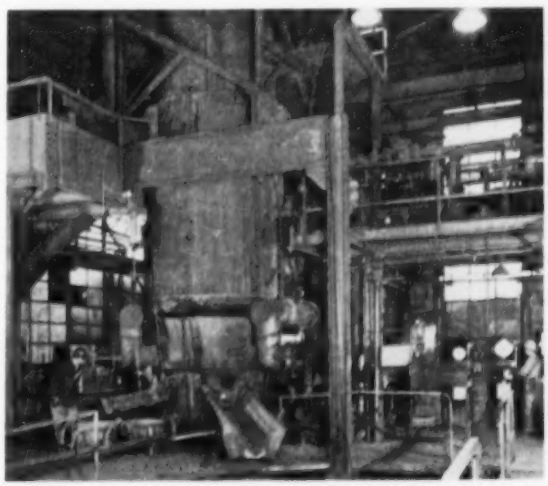
Metal composition in such a furnace is usually uniform within the limits of accuracy of chemical analysis. Slag composition is likely to show considerable variation for basic furnaces. For oxidized fluid slags, the magnesia content is often quite high near the banks unless the slag is stirred frequently. In the case of reducing slags, slag under the arcs will be fluid while that near the walls is stiff and not near equilibrium with the metal.

The major consideration in determining the size of an arc furnace for a research laboratory is the availability of power and demand charges for electricity. If a furnace has good electrode controls, impedance of 40 pct or more, and lime additions are made to the arc pools as soon is they form, furnace operation should cause little or no disturbance of lights where the transformer capacity is four times the kva drawn by the furnace.

The total cost for a series of melting tests in which a 500-lb arc furnace is used is not appreciably more than for much smaller melts, when supervision, chemical analysis, and report preparation are included.

Blast furnaces

Experimental blast furnaces have been operated at various times in the United States and Europe. One of the recent operations' is the low-shaft blast furnace at Liege. An experimental blast furnace at the Bureau of Mines, Pittsburgh, reproduced industrial operations at comparable fuel rates when abnormally high blast temperatures were used to



The experimental blast furnace built by the U. S. Bureau of Mines at its Pittsburgh station.

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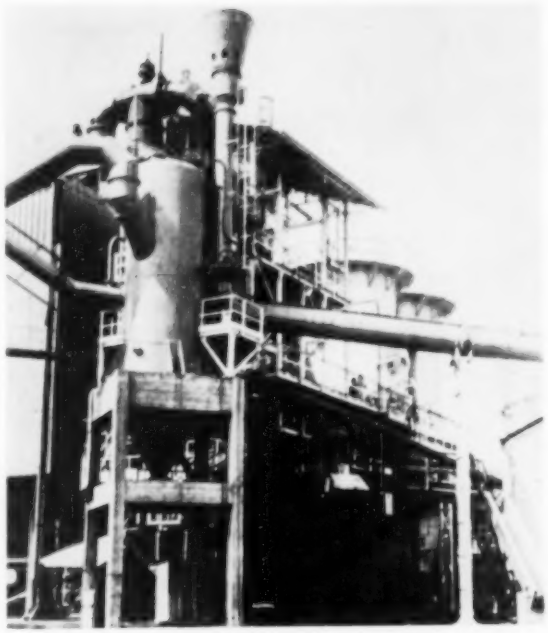
offset heat losses.[6] Experience gained with a smaller predecessor permitted the design of this efficient furnace.

A major problem in the design of small pilot blast furnaces is to avoid excessive heat loss. To illustrate the basic difficulties involved, we can consider heat losses in a pilot furnace scaled to 1/10 the size of an industrial furnace, which would have about the capacity of the Bureau of Mines furnace. The volume of the pilot plant furnace would be 1/1000 of a commercial furnace. If the retention time of the solids were maintained the same as for a large furnace, the capacity would likewise be 1/1000 of a large furnace. However, the surface area of the inside of the furnace through which heat is lost has only been decreased by a factor of 1/100. Consequently, for the same rate of heat loss per square foot of lining, the heat loss per ton is ten times greater than for an industrial furnace. If the lining thickness were decreased in proportion to the scale factor, the ratio of heat losses per ton would be 100. While the heat loss from the upper parts of the blast furnace can be decreased by use of insulating brick, efforts to decrease the heat loss from the high-temperature zone of the bosh and hearth result in rapid lining erosion until the heat loss has again been increased to a high figure. Refractories are only stable in the bosh as long as slag will solidify on them, and the heat loss after stable conditions have been reached will not vary greatly with the type or thickness of refractory used to line the furnace. For example, when the bosh of the experimental blast furnace was lined with fire brick, this eroded to a stable thickness of about ¾ in. whereas with a carbon brick lining, the stable thickness was about 2 in. Nevertheless both linings resulted in the same heat loss.

Because of this high heat loss from the bosh and hearth of an experimental blast furnace, the heat balance in this zone determines whether the experimental furnace will have fuel rates comparable to an industrial furnace. Fortunately, the high heat loss from this zone for an experimental furnace can be offset by the use of blast temperatures higher than those employed by industrial furnaces, so comparable fuel rates can be obtained.[7]

A second important consideration is the size of the raw materials. If the particle size is decreased with constant gas velocity, dust losses will be excessive. Furthermore, if the total pressure drop (expressed in lb per sq ft) through the stock column exceeds its weight (expressed as lb per sq ft of cross section), the charge will be supported by the blast and will not descend smoothly. Hence low blowing rates would be necessary with small particles. If the use of small particles and low blowing rates does not result in a corresponding decrease in the height of various zones, their use is undesirable in that the rate of heat production is decreased in relation to the heat lost unless the blast is oxygen-enriched. Consequently, thermal considerations require the use of moderately large raw materials which are not scaled in proportion to the furnace size.

As long as the maximum particles are small in relation to the furnace diameter, the walls do not exert much influence on the flow of gases and hence the scale factor that is used for the furnace need not apply to the particles. Therefore, if the major purpose of the work is an investigation of raw materials and a determination of fuel rates, the experimenter would be inclined to choose a gas velocity at some section of the furnace or solid retention time comparable to an industrial furnace, and then use particle sizes that would give a pressure drop below the critical value at which the stock column will not descend smoothly. For the Bureau of Mines furnace, fuel of about 2-in. maximum size and commercial size ore with the +2-in. particles removed proved very satisfactory. Such particles sizes do not, however, give a raceway in front of the tuyeres used in the exprimental furnace comparable to a large furnace. Consequently, an investigation of those factors that depend on the raceway in front of the tuyeres is probably conducted better with a non-operating model.



The low shaft blast furnace at Liege, Belgium, showing dust collector in the foreground.

To obtain both gas velocity and solid retention time equal to a commercial furnace would require that the pilot plant furnace have a comparable height. Such a tall furnace of small diameter would be inconvenient and probably would not permit smooth descent of the charge as a suitable batter of the walls could not be maintained. However, this difficulty can be resolved by operating a low furnace at different blowing rates to satisfy each condition. By following this procedure, it was observed that for the pilot plant furnace both blowing rates resulted in similar operations. Hence it appears that the inability to have both gas velocities and solid retention time equal to an industrial furnace is not a serious limitation.

While a pilot plant blast furnace reaches stable conditions more rapidly than a commercial furnace, three days of operation were generally necessary to obtain reliable data on the effect of a change of burden or operating conditions.

Essentially all the same jobs must be performed in operating a pilot plant furnace as an industrial furnace, so the size of the crew is not greatly different. Labor costs are not influenced appreciably by the size of the pilot plant blast furnace. Raw material costs are offset by the value of the metal pro-

duced. Operating expense for an experimental blast furnace runs about $1500 per day. It is hardly worth embarking on a program of less than four months' duration costing about $180,000. The construction cost of a pilot plant blast furnace of 3-ft hearth diam producing from 12 to 17 tpd is about $500,000. This is the smallest size furnace for which the operations are comparable to an industrial furnace, if shaft reduction is important. A smaller furnace gave good results when smelting open-hearth slag that would not reduce appreciably in the shaft, but worked poorly on iron ore.

Open-hearth furnaces

An experimental open hearth of 4 tons capacity has been successfully operated at the Jones and Laughlin research laboratories for many years.[5] This is a nonreversing type of furnace with two air-fuel ports at one end designed for rapid combustion to give a high heat release from the flame. The furnace at the Bureau of Mines' is of similar design except that it is made to tilt. Both furnaces use silicon-carbide recuperator tubes. The three pass recuperators at the Bureau of Mines heat the combustion air to 1600°F, but the heat loss in the ducting is 200°F, so the air is only 1400°F at the burners. This furnace operated very well for several weeks after a refractory repair, but as the refractories became thin it was necessary to oxygen-enrich the air for satisfactory melting rates.

Furnaces of the type described with burner ports at one end are not suitable for the study of open-hearth combustion problems, as the flames are very different from those encounted in industrial furnaces. Hot models which do not melt metal appear more suitable for the study of gas flow and combustion problems. Several such furnaces have been built; in England, on the Continent, and by U. S. Steel in this country.

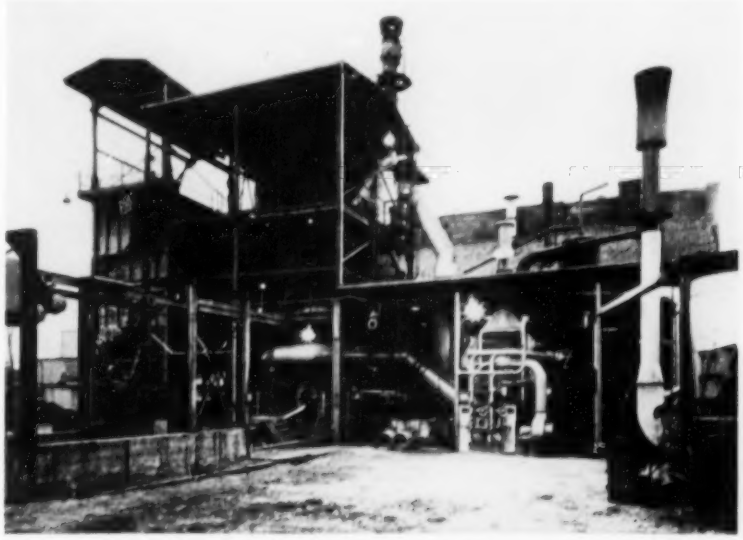
Pilot plant open-hearth furnaces have a high heat loss per unit of combustion volume. For furnaces of similar shape, the area through which heat loss occurs varies as the square of the dimensions, while the combustion volume varies as the cube. Consequently small pilot plant units should be designed for a minimum heat loss consistent with satisfactory refractory life and for flames giving a high rate of heat release. The use of insulating brick as a backing for the normal refractory is desirable because of the low thermal capacity. However, for insulated furnaces, portions of basic refractory under considerable load or exposed to flame impingement or slag splashing will erode rapidly. Sudden failure occurs when the interface between the basic brick and insulation reaches the softening point of the mixture of acid and basic material. Therefore premature refractory failure limits the location and thickness of insulating brick that can be used.

Another means of providing the maximum combustion volume for a given heat loss is to have the furnace approach spherical shape. For pilot plant open-hearth furnaces this means a greater decrease in length than in other dimensions. The rate of heat release per square foot can be increased by use of high-heat fuels, rapid mixing of air and fuel, high air preheat, or oxygen enrichment. An air preheat in excess of that used by industrial open-hearth furnaces would be desirable for a pilot furnace, but a convenient means of achieving this is not known. Oxygen enrichment of the combustion air is desirable but the cost of oxygen adds considerable to the total operating expense if the oxygen is purchased in small quantities.

Reactions and hence changes in metal and slag compositions occur much more rapidly with small baths than in large operations. Unless the bath has a weight of two tons or more, it is likely to melt low in carbon, if appreciable low carbon scrap is used. The speed of reactions determines the minimum size of bath, whereas the relation of combustion volume to heat loss determines the furnace size.

Converters

The author's experience with pilot plant converters has been limited to side-blown basic converters of 500 lb and 1-ton capacity. The major problem with such small units is the high heat loss from the converter and ladles used to transport metals, which often results in excessive skulls, especially if delays are encountered. The high heat loss can be offset by oxygen enrichment of the blast at the expense of rapid tuyere erosion and dense fume if too much oxygen is used. Another method is to blow metal with a higher-than-normal content of



The low-shaft furnace pilot plant built by Demag-Humboldt Niederschachtofen GmbH, for the utilization of coal-iron ore briquettes. A 100 tpd plant based on this design is now being built in Germany; it will be described in the November 1957 JOURNAL OF METALS.

silicon, manganese, or other element that will produce more heat than the oxidation of carbon and iron per unit of oxygen blown. This procedure may, however, make interpretation of the data difficult. The refractory of the converter can also be backed with insulating brick in areas not subject to rapid erosion. A converter of about 1-ton capacity appears to be the minimum satisfactory size when air blowing metal of the composition normally used in this country. With enrichment of the air to about 30 pct O_2, or when oxidizing metal of higher-than-normal content of silicon, manganese, or phosphorus, a 500 lb converter can be used.

Small converters are suitable for studying the effect of operating conditions on metal and slag composition. They can also be used for evaluating furnace refractories and the effect of changes in design on refractory life.

Relation to industrial plants

The preceding discussion of specific types of pilot plants together with data on a large variety of pilot plants that have been published in recent years will now be used as a basis for developing general methods of design.

A pilot plant can be related to an existing or proposed industrial plant in several different ways as listed below:

Scaled Model: In this method of design certain major dimensions will be in definite proportion to those of an industrial plant. It is usually not desirable, however, to scale all dimensions, as, for example, the refractory thickness. If the particle size of raw materials is small in relation to the furnace dimensions, the scale factor generally need not be applied to particle size.

One or a few of the most important operating variables such as production per cubic foot, retention time, and rate of material travel; or known relationships such as friction factor, pressure drop, and rate of heat transfer, can be set the same as for an industrial plant. The remainder must then necessarily differ from those of an industrial plant, usually by some power of the scale factor. This may prevent the achievement of satisfactory operations. While the method of scaling works well for the design of non-operating models intended to study specific relationships, serious difficulties are likely to be encountered in applying the procedure to the investigation of entire processes by means of operating pilot plants.

Section of an Industrial Plant: In this approach the pilot plant would be designed to simulate a section taken from an industrial plant. As an illustration, a pilot plant might have a cross-sectional area at any length position which was a small fraction of that of the industrial plant, but length, particle size, gas velocity, and retention time could all be the same as for the large equipment. For example, a pilot sintering tray can be readily constructed on this basis. For such design, it would be important to determine that the wall did not have a great effect on the results. The application of this principle could in some cases lead to fantastic proportions and excessive heat losses. A pilot plant blast furnace designed by this method might be 3 ft in diam and 80 ft high, and therefore impractical.

In the case that an industrial plant contained a large number of similar units, as, for example, burners, tuyeres, etc., the pilot plant might be designed for one or several units of the same size as used in the industrial plant with production, gas flow, and cross-sectional area proportional to the relative number of units.

Special Design: Often neither the scaled model nor the section of an industrial plant method of design would give a pilot plant capable of satisfactory operations. In this case, the process can be analyzed on the basis of known relationships such as heat balance, reaction rates, gas velocity, heat transfer, and material flow, and each portion of the equipment can be designed to perform its major function most efficiently. For example, the thickness of insulation and the amount of heat input required would be established by the heat balance. Gas velocities might determine the cross-sectional areas and the size and number of gas ports or tuyeres. The length or height of the equipment would be influenced by reaction rates, heat transfer, and material flow. While a pilot plant designed on this basis may have a physical appearance considerably different from the industrial plant studied, the major physical, and thermodynamic relations are all kept in reasonable balance so that efficient operation will result.

Importance of heat loss

Pyrometallurgical pilot plants usually suffer from excessive heat loss because of the large surface area through which heat loss occurs in relation to the working volume. Consequently, scale factors should not be applied to the thickness of the refractory and material of high insulating value should be used. If too much insulation is applied, however, rapid refractory erosion is likely to occur in parts of the equipment so that it is often not practical to build pilot plants with the low heat loss desired. Furthermore, thick insulation may require several days to approach thermal equilibrium, and is therefore of little value for short-time operation.

The heat losses from pyrometallurgical equipment can usually be estimated to a fair accuracy from simple measurements and calculations. For operations conducted over a narrow range of temperatures and for which the necessary heat can be adjusted without altering the important process variables, adequate correction for heat loss can usually be applied to pilot plant data for comparison to industrial operations. An example of this is in electric smelting tests.

For processes in which the heat production is related to the normal reactions or in which heat is extracted over a wide range of temperature, it is often desirable in pilot plant research to alter certain operations, raw materials, or temperatures to produce extra heat in order to compensate for higher heat losses. For example, air can be oxygen-enriched or higher air preheats can be employed than for industrial operations while maintaining similar gas flow or fuel consumption.

The minimum size of pilot plant that can be operated efficiently is usually determined by heat losses in relation to rate of heat production or transfer.

References

[1] P. Coheur: Ore Fines Utilized in Lowshaft Furnace to Produce Thomas Pig Iron, JOURNAL OF METALS, August 1955, vol. 7, pp. 872-876.

[2] R. C. Buehl and M. B. Royer: Low Fuel Rates with Coke-Anthracite Mixtures in Three-Foot Blast Furnace, JOURNAL OF METALS, April 1956, vol. 8, pp. 432-438.

[3] H. K. Work and W. R. Webb: Operation of an Experimental Open-Hearth Furnace, *Blast Furnace and Steel Plant*, 1945, vol. 33, p. 959.

[4] R. C. Buehl, R. J. Leary, and E. J. Ostrowski: Recarburizing Heats with Coal or Coke Injected by Compressed Air, *Proceedings*, National Open Hearth Steel Conference, 1953, vol. 36.

The Paris Sintering Conference — A Summary

The first International Sinter Symposium was held in London in November 1953. Since then, important developments in iron ore sintering have been achieved. Therefore, IRSID organized the Second International Sinter Symposium in Paris, May, 1957.

by J. Astier

THE Second International Sinter Symposium was attended by some 300 specialists from France, Germany, United Kingdom, Belgium, Luxembourg, Netherlands, Italy, Norway, Portugal, Sweden, Union of South Africa, and the United States. Delegates from the Soviet Union, although unable to attend, sent four papers putting the total number of papers submitted to 34.

The official report, including all papers together with their discussions—in French with summaries in English and German—will be published at the end of 1957 by IRSID.

Mechanism of the sintering process

At the previous sintering symposium, attention was drawn through BISRA—British Iron and Steel Research Association—to the air volume, bed permeability, and especially to the notion of specific air volume, that is the quantity of air necessary for the sintering of 1 ton of mix. In Paris, these concepts were the subject of two papers from BISRA: a report on the laboratory research of Voice and Wild, and the conclusions of an industrial test of Ridgion and Bates. A further advance in the study of heat transfer during sintering was made, and from recent research, Voice and Wild believe that the specific volume of air is determined mostly by heat transfer phenomena and not by the carbon combustion requirements.

Two papers referred to desulfurization, one of Baldwin and Burgess of BISRA and the other of Auxenfans and Turpin of IRSID. They show extremely good desulfurization obtained by the sintering process, whether the sulfur be in the form of sulfide or of sulfate. Their research has also described the mechanism of the desulfurization process and the final mineralogical state of the residual sulfur.

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During the discussion, debate arose in regard to the removal of sulfur during agglomeration in a rotary kiln. Such desulfurization seems to be rather low in the small kiln of the Esperance-Longdoz works in Belgium, but it appears to be better in the large rotary kilns of ARBED in Luxembourg. Berg of F. L. Smidth & Co. of Denmark indicated that good results were obtained when treating pyrite cinders in rotary kilns in Sweden.

A series of tests made at IRSID have shown the influence of suction on the sintering process. Menuet-Guilbaud, Auxenfans, and Folie have clarified the concept of specific air volume per ton of mix and shown that this volume is not strictly constant. It appears also in their research that the mechanism of combustion of carbon was influenced by variations of the suction.

Sinter quality

IRSID research work on the mineralogical structure of Lorraine iron ore sinter was presented by Turpin, Angeli, Pompey, and Robert. The problem has been well approached and, in some particular cases, completely resolved by the use of X-ray and selective chemical analysis.

Numerous studies of the physical properties of sinter, particularly size analysis and mechanical resistance, were undertaken in laboratories and plants. The paper of Michard and Matraski of IRSID, a tentative interpretation of shatter tests or drum tests, added to the understanding of the nature of sinter and helped to define quality indices.

Boned-Sopena of the Instituto del Hierro in Spain showed how to apply these indices to the preparation of self-fluxing sinter. Klein of the South African Iron & Steel Corp. pointed out a typical situation where additions of lime have had a good effect on sinter quality. He emphasized the difficulties of testing quality, pointing out that it is only by industrial tests in blast furnaces that a classification of the different kinds of sinter can be made.

Sinter plant operation and design

This was the subject of 14 papers, to which must be added the three communications from the USSR which arrived after the session. One related mostly to the increasing sinter capacity in the USSR: 6 million tons per year in 1940, 12 in 1950, and 40 in 1956.

Preparation of the sinter mix: Weilandt of Klockner Huttenwerk Haspe in Germany and Sironi of the Finsider group in Italy gave interesting details of the use of finely ground pyrite calcines and magnetite concentrates. The paper of Parfenov of the USSR completed this information, indicating that in the USSR pelletizing is not used to agglomerate magnetite concentrates, even when finely ground. It seems that they are rather looking for improvements of classical sintering by preheating of the mix, additions of fluxes, etc.

Research on ignition: This was the object of quite a number of papers. It is symptomatic of the general interest aroused not only in classical ignition, but also in the eventual use of preheated air. This can be used for two different purposes: to decrease the consumption of solid fuel—eventually replaced by gas—or to get a better sinter, especially for the top layers. Bell, of the Dorman Long firm in the U. K., showed the interest of a quick and brutal ignition with coke-oven gas, for the apparatus and for the sinter quality. The paper of Colvin of Stewarts & Lloyds of the U. K. and Rausch and Meyer of the Lurgi firm in Germany concerned an increase of ignition time. They showed that it can be a means of reducing requirements of solid fuels. But the exact mechanism of that process is not yet clear, and some widely differing results have been noticed, mostly in the rate of production.

Obviously the addition of calories from hot fumes will be mainly beneficial to the upper layer of the mix; so, the greatest interest of this process would be in the case of a two-layer practice, each layer having different carbon content. The effect is especially strong, if all the screened sinter comes from the upper layer, as in the practice proposed by Jennings of the Huntington-Heberlein firm in the U. K. In this case, the lower layer is used only for roasting the ore which is sintered by a second passing on the strand, this time as the upper layer.

Recent plant improvements: Rudkov of the USSR gave operating results at the Dzerzinski sinter plant. Colvin of the U. K. related the improvements made since 1953 at the Corby sinter plant. The results are remarkable: increase of production of 70 to 80 pct and decrease of the consumption of coke breeze of 45 pct. The third paper, from Robertson, Haslam, and Siddons of the United Steel Companies in the U. K. related a series of tests made at Appleby-Frodingham. The work shows the performance of a strand, taking into consideration several variables such as the circulating load and the characteristics of the fans.

Substitution of solid fuels: With coke breeze in short supply in many countries, emphasis was given to its substitution by other solid fuels. Michard of IRSID gave a method of comparing these fuels, thus making it possible to know the equivalence between several kinds of coal, charcoal, and coke breeze. Many sinter plants are already using such substitute fuels: in the Saar, coal slimes are used, and anthracite fines are employed in the U. S. and in the USSR. Rudkov's paper relates such a process at the Dzerzinski plant in the USSR where other fuels have also been successfully tested.

Blast furnace practice with high sinter burden

Patchett of Dorman Long of the U. K., McLean of the Steel Co. of Wales, and Klein of the South African Iron & Steel Corp. presented papers relating to the use of sinter with high iron content. Industrial tests at Dorman Long gave a linear decrease of coke rate with increasing sinter percentage in the burden. The same conclusions were reached by Rice of Koppers Co. and Adariukov of the USSR. But this seems to contradict the findings of Squarcy who found that the coke rate decreased at a decreasing rate with higher percentages of sinter in the charge.

From the decrease in coke rate it can be concluded that the pig iron production can be increased with high sinter burden; however, it is not always possible to attain the theoretical production due to insufficient blowing capacity, especially with the necessity of using high blowing pressures.

All speakers agreed that improvements in pig iron quality followed when using high sinter burdens.

During the discussion, J. Miller of New York quoted some figures about the advantages of using sinter in electric furnaces of the Tysland Hole type. Results from the Mo-I-Rana plant in Norway are in good agreement with previous figures from Domnarvet in Sweden.

Charging low-grade ore sinter: In the last session there was a discussion on the use of sinter made from low grade iron ores from Lorraine or Northants and Frodingham in England. Conclusions of the papers by Rondet of the Chiers firm, Roederer of Lorraine-Escaut, and Brun of Kuntange—all French steel firms—are as follows: first, the coke rate decreases by 400 lb per short ton of iron when switching from raw ore to prepared burden—screened ore and 30 pct sinter from fine ore—this saving can be 500 or 600 lb per short ton of iron when using up to 50 or 65 pct in the burden; second, pig iron production can be increased by 50 pct; third, flue dust production is considerably reduced; and, third, the quality of the iron is greatly improved.

There was a great deal of discussion about the paper by Paquet of ARBED, Luxembourg, relating to a comparison between the use of sinter and rotary kiln nodules. Conclusions from Paquet did not show much difference between coke rates of the blast furnace using sinter or nodules. Top gas analyses were, however, different and several speakers drew attention to that point which seems to indicate some advantage for sinter.

The last paper was an outstanding contribution from Ayres about the Appleby-Frodingham plant in the U. K. It gave many conclusions from the operating practice of this world-known plant where 100 pct sinter burden has been used for several years.

At the close of the conference one of the British delegates declared that, "While much progress has been made, there is room and need for much more. Perhaps the outstanding requirements are to increase outputs by pre-pelletizing or some technique of increasing bed permeabilities; there should be many more plant-scale modifications to reduce the fuel requirements, particularly of coke breeze; and there should be more emphasis on producing self-fluxing sinter."

[1] Iron and Steel Institute, London: *Symposium on Sinter*, Special Report No. 53, March 1955.

Since the organization of ECSC five years ago, it has been concerned with the relatively weak effort directed toward technical research by the steel industries of the Community, compared with the importance which is attached to metallurgical research in the U. S., the USSR, and the U. K. Article 55 of the Treaty instructed the High Authority to encourage technical research by coordinating the work of existing organizations and by granting financial aid.

European Metallurgical Research—

Fundamental to the Coal and Steel Community

by F. Weston Starratt

Headquarters building of the High Authority of ECSC, in Luxembourg.

IN April 1953, a Commission on Technical Research was created by the High Authority of the European Coal and Steel Community. Its members are the representatives of the research institutes of Belgium, Luxembourg, France, and Italy, the Secretary-General of the Verein Deutscher Eisenhuttenleute in Germany, and the Director of the Blast Furnace Research Laboratory of the Royal Dutch Iron & Steel Works. An observer is sent from BISRA—British Iron and Steel Research Association.

The High Authority, under the terms of the Treaty, is instructed to promote metallurgical research by two means: first, to organize all appropriate contacts between existing research organizations, and second, to encourage the financing of research schemes, in common with other organizations, by granting direct financial aid.

The metallurgical research projects thus far granted aid have all been financed in part by steel firms or associations, and the financial participation of the High Authority has varied between 15 and 55 pct. These research subsidies are proposed either by the High Authority itself, taking into account its general objectives for metallurgical expansion, or by persons, firms or associations.

The first research program

The first program for promoting metallurgical research was adopted in 1953. It included five projects:

1) comparative trials of various types of coke in blast furnaces,

2) the trial operation of a blast furnace under pressure,

3) a series of rolling mill trials,

4) use of silica bricks for the arch of open hearth furnaces, and

5) participation in the operation of a station for studying open hearth flames in the Netherlands.

Proposal number two has been put off to a later date, but items number three and four have been carried through in plants and laboratories, and the reports will be ready by the end of the year. The contribution of the High Authority to all these projects has amounted to about $1.6 million, stretching out to the end of 1958.

In regard to item one, the problem of supplying the blast furnaces of the Community with adequate grades of Ruhr coking coal has been critical. In France, various techniques are being devised to produce adequate coke from various grades of Lorraine coals. Saar coals are also of generally lower coking qualities. Thus, the High Authority has granted the

Forges et Acieries de Dilling in the Saar the sum of $1 million to effect comparative industrial trials of the hard cokes of the Ruhr and the weaker cokes, made in part from coal of lower coking qualities. The experiments will be made in two indentical blast furnaces operating at the same rate, but the project has been delayed on two occasions by the difficulty of assuring regular supplies of raw materials of constant quality.

In regard to item four, the High Authority has given out $278,000 to effect the systematic trials of silica bricks in the arches of a group of open hearth furnaces in the Community.

In regard to item five, the International Flame Committee, created in 1948, has undertaken experiments at Ijmuiden in the Netherlands, with the object of improving the heat efficiency of fuels utilized in the steel industry, particularly in open hearths. In July 1955 the High Authority granted the sum of $105,000 to the organization which has permitted the construction of an experimental furnace. For further details of the Ijmuiden project see JOURNAL OF METALS, February 1957, p. 252.

Lack of adequate coke supplies—today's number one problem

With the program for considerably expanding the Community's steel production faced with limited supplies of scrap and a coal output which can not be greatly expanded, economy in the use of coke has become a major objective of the High Authority.

The work of the Commission on General Objectives has emphasized that the development of the desired level of steel production must be based on a proportionally greater consumption of pig iron than at present. But pig iron will not be available in sufficient quantities without an important expansion of blast furnaces and coke-ovens, conditioned itself on the output of coal of coking quality. These investments, particularly high with respect to blast furnaces and coal mines, can be reduced to the same extent that the consumption of coke required to produce a ton of pig iron can be reduced. Thus, the Commission on General Objectives has affirmed with insistence that "it is from now on necessary to redouble the technical efforts in order to obtain a substantial reduction of the coke rate in the blast furnaces".

In the course of a meeting held in July 1956, the Commission on Technical Research emphasized the importance of research undertaken in view of perfecting processes permitting a reduction in the consumption of metallurgical coke per ton of pig iron, and more generally per ton of steel produced.

Taking into account the proposals of the Commission on Technical Research, the High Authority has thus far made two research grants: 1) a credit of $850,000 to be used over three years in order to operate the Liege low-shaft furnace as a reduced-scale blast furnace on an experimental program designed to test methods of reducing the coke rate; and 2) a credit of $650,000 to be given out in stages to various research projects for reducing coke consumption. The object of this technique, designating the objective but reserving selection of the beneficiaries until a later date, is to encourage initiative in this domain and finally choose the most adequate proposals. There is special interest in the use of 100 pct agglomerate, the enrichment of certain low grade ores, and the direct reduction of rich ores.

After the successful operation of a blast furnace on 100 pct sinter at the Appleby-Frodingham plant in England for several years with remarkable reduction in the coke rates, the High Authority has become quite interested in promoting experimental trials of this type within the Community. Already, in the Saar the Forges et Acieries de Dilling has operated blast furnaces on charges made up of 88 pct sinter and has achieved good results.

At present the Commission on Technical Research is studying one proposal for the injection of gasified fuel into the blast furnace, and a second project for the successive testing of liquid fuel and of gasified fuel in the blast furnace. Proposals for a new technique for the production of low-temperature coke are also under examination.

A further proposal for a new type of low shaft furnace designed by the Lubatti firm in Italy is being considered. It includes a radical departure from traditional low shaft furnace design in that vertical tuyeres, from the top of the furnace into the crucible at the bottom, are to be used to supply either air or oxygen enriched air.

Direct reduction processes to be tested

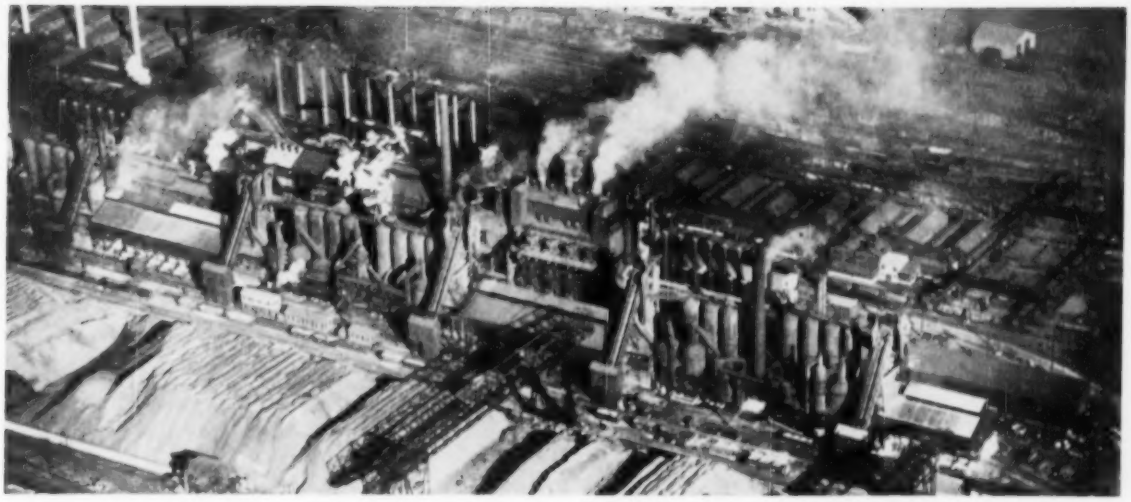
The Commission is greatly interested in processes which bypass the blast furnace completely. Already some funds have been granted to the Krupp-Renn plant being built at the site of the old Krupp plant in Essen, Germany. This plant, to be put into operation in 1958, will have six Krupp-Renn furnaces with a length of 60 meters, producing together some 300,000 tons of iron nodules per year. It will be larger than the present operation at Salzgitter in Germany, and possibly one of the largest in the world. The High Authority of ECSC expects through its grant to obtain technical information on the production and usage of this material.

The production of H-Iron, that is the direct reduction of rich ores through the use of hydrogen, has greatly aroused the interest of the Commission on Technical Research of ECSC. In France, near Nantes, an experimental H-Iron plant is being planned near oil refineries in that district. It will be the undertaking of a completely new firm called the Societe Metallurgique de l'Adour. The High Authority is expected to grant funds to this project.

Refractories, casting, and other fields

While the central point of research at present being sponsored by the High Authority is aimed at the reduction of coke consumption, research in certain other fields is also being contemplated, for example a study of silico-alumina bricks in the construction of recuperators for open hearth furnaces.

The total financial aid thus far granted by the High Authority for technical research projects concerning iron and steel has amounted to slightly more than $3 million. But this appears to be only the beginning of a program whereby the High Authority of the European Coal and Steel Community is encouraging metallurgical research in the plants and laboratories of the six countries making up the Community. There are no provisions for the High Authority to set up its own laboratories or research stations, but it can be expected that an ever increasing financial interest will be devoted to projects designed to improve and expand the production of steel in Europe.



Aerial view of the Aliquippa Works of Jones & Laughlin Steel, showing five blast furnaces.

Blast Furnace U.S.A.

III. From Falling Creek to Zug Island

Bituminous coal furnaces give way to coke, and by 1880, the American iron and steel industry was growing at a tremendous rate. In the twentieth century, the number of operating blast furnaces was cut in half while pig iron capacity more than doubled.

by M. O. Holowaty and C. M. Squarcy

Bituminous coal furnaces

Attempts to relieve the shortage of charcoal by the use of bituminous coal in American furnaces began quite early. Use of bituminous coal in the blast furnace was restricted to areas lacking anthracite deposits but rich in deposits of bituminous coal. The largest concentration of bituminous coal furnaces was in Western Pennsylvania, West Virginia and Western New York state. Other areas included Kentucky and southern portions of the states of Indiana and Illinois.

The first trials were made in Pennsylvania around 1780. Gradually several more furnaces began charging coal with their burdens as a partial substitution for charcoal. These so called *cheaters* were numerous, especially in Western Pennsylvania, which around 1810 began to expand its ironmaking capacity to catch up with the Lehigh Valley and the Schuylkill.

According to the existing references, complete bituminous coal burdens began to be used in this area only around 1840 when the ironmakers hastily adopted the hot blast apparatus introduced from England.

The majority of these furnaces were built, however, after 1844 when an extensive experimental program, carried out at the Shenango Steam and Water Hot Blast Charcoal, Coke and Raw-Coal Furnace produced favorable results, with coal containing up to 35 pct volatile matter. The furnace was located near the Shenango River on the Lackawannok Run, five miles northwest of Mercer, Pennsylvania.

It was built, owned, and operated by David Hogeland of Mercer. The first furnace was built in 1836 or 1837 as a charcoal furnace. Soon, however,

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difficulties in charcoal supply became apparent and Hogeland began experimenting with coal. The original Shenango furnace, known also as Big Bend Furnace, was 6 ft across the bosh and 28 ft high. Blast was furnished by a large water wheel.

Hogeland was a Dutch storekeeper who specialized in trade with coal miners and ironmakers of the Lehigh Valley. For unknown reasons, he abandoned his store and profession and went into partnership with Richard Shippen and Jacob Black, who jointly operated the Shippenville Charcoal Furnace at Shippenville, Pa. Hogeland learned the iron trade from Robert Montgomery, Manager of the Shippenville furnace and for many years thereafter his friend and ardent supporter. David was apparently in his fifties when he decided to investigate the iron smelting process in the blast furnace. Equipped with a keen, investigative mind he wanted answers which no blast furnace master could provide. Was screening of ore advisable? Could it be that limestone they were using was not taking out sulfur properly?, and above all—why could not bituminous coal be used for burdening the furnace?

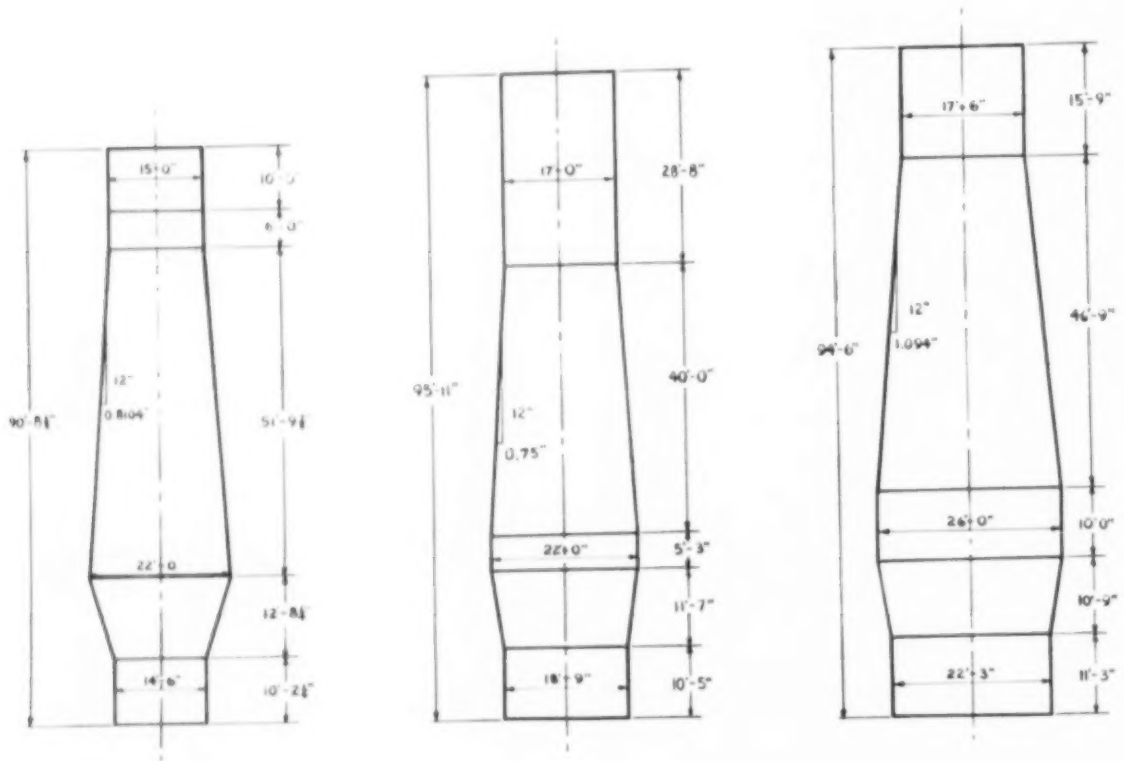
To find the answers, he finally decided to build a small furnace in Mercer County. Big Bend furnace was blown in 1837, and judging from its production records its owner was not wasting time with experimentations. Charcoal, various coals, and even the peculiar spongy fuel known as coke were tried on the furnace, only to prove that charcoal was the only fuel which could be used successfully. But Hogeland was not ready to give up.

Strange stories were coming to Western Pennsylvania's coal basin that winter of 1839; an Englishman was building an anthracite blast furnace at Allentown. The neighboring furnace masters paid no attention to the new fangled hot blast idea, and even Hogeland seems to have hesitated, for he delayed the trip east until the summer of 1840. What he saw at Allentown's Thomas furnace, however, made him enthusiastic about the hot blast and his coal. Having ordered the necessary supplies and equipment, Hogeland went home and began making the required changes on his blast furnace. The hot blast equipment was installed in the spring of 1841 and water wheel was replaced by a steam blowing engine, recommended by Thomas. Hogeland also ordered several hundred tons of Eastern Pennsylvania anthracite and secured piles of various coals which he intended to investigate. Late in 1843, coke made in beehive ovens was also included in Hogeland's program, apparently because it was available from nearby Mercer.

Hogeland's furnace was kept in operation until the summer of 1884 when it was torn down and rebuilt to a 7-½ ft bosh, 36 ft high unit. During various stages of Hogeland's experimentation the Big Bend blast furnace remained the center of attraction of many blast furnace men who came from far away to get expert advice and to see a real 100 pct coal furnace in operation. This explains the activity in the field of coal blast furnace construction around 1844.

Hogeland, the Pennsylvania Dutchman who made the bituminous coal furnace a reality, received the answers for which he was searching. Between 1845 and 1854, he operated his furnace just as he always thought he could—with either charcoal, coke, raw coal or anthracite or any mixture of them. The only available production record of this period shows that the furnace produced 1700 tons in 1854.

Considerable information could be gathered on the number and names of furnaces built and operated like Hogeland's Big Bend Furnace. All these furnaces were considerably larger than the original Hogeland coal furnace and consequently their pro-



ductive capacities were much higher. The average annual production ranged from 4000 to 5000 tons as compared to the record production of 1700 tons made on the Big Bend furnace.

The erection of furnaces in Indiana and Illinois was caused by the movement of the American population to the West which reached its peak between 1870 and 1880. The pioneers in the newly settled territories required iron and steel for the tools and simple machines which they had. Thus the construction of the furnaces in Indiana and Illinois was a natural solution to their iron problem, since the coal fields of these two states besides Missouri formed the Western boundary of the American coal deposits. Here about 10 furnaces were in operation in 1855. Two in Iron County, three in Francis, one each in Crawford and Franklin Counties.

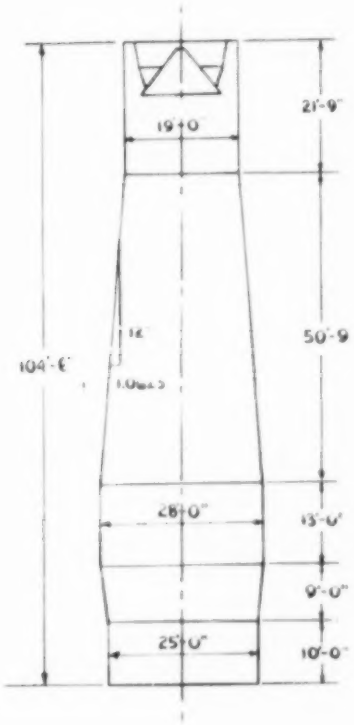
The most famous plant was the Iron Mountain Works of James Harrison, J. J. Scott and T. James who were also known as *The Three Jimmys*. Their first blast furnace was built in 1846, the second in 1850 and the third in 1854. The Iron Mountain plant was probably the most prosperous of the midwest.

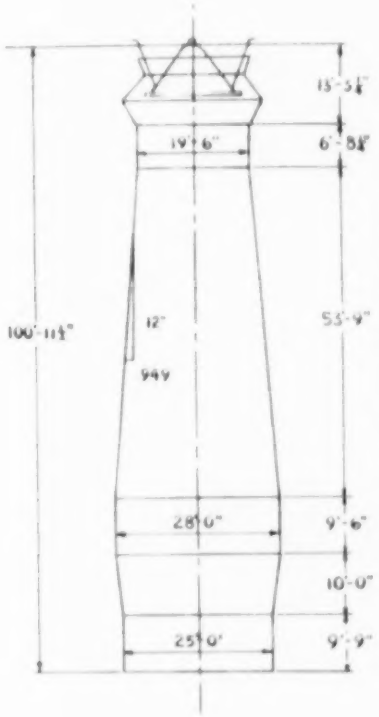
The relatively short periods of existence of these furnaces does not appear unusual if one realizes the most serious drawback of their locations—the shortage of iron ore. Contrary to the iron industry of Ohio and Pennsylvania, Indiana and Illinois had no deposits of iron ore. Consequently, it had to be brought in by rail and horse wagons. The economy of these furnaces was such that they could not compete with Eastern iron which moved westward in increasing quantities as the steadily expanding network of railroads also moved west. The number of the blast furnaces in Indiana and Illinois was never large. The peak was reached in 1874 when Indiana had 12, and Illinois 11 furnaces in operation. The number kept decreasing regularly, however, and in 1890 there were only three furnaces in Indiana and four in Illinois.

The age of coke

When the Pennsylvania legislators in 1836 passed the act for encouragement of the manufacture of iron with mineral coal, they included in the bill use of "coal or coke" fuel, only after lengthy explanation by Mr. F. H. Oliphant of Fayette County, Pa. Mr. Oliphant was obviously referring to native mineral coke which was found occasionally in the coal beds of Pennsylvania and which he used quite frequently, since he and his brother purchased the Hayden furnace in 1797 or 1798. Mr. Oliphant, who was in charge of the blast furnaces at the Oliphant Brothers Iron Co., developed a strong interest in the peculiar coal that was delivered from time to time at the works. Some pieces of this coal were larger and harder than ordinary coal and were very porous. The *coak* coal did not ignite easily; Oliphant found that the best way to ignite it was by burning it with coal, and then it did not burn with the long yellow flame of coal but rather glowed intensely for a long time. Oliphant began to charge coke into his charcoal furnace sometime around the turn of the century. As far as could be deduced, only small amounts of coke were mixed with the charcoal burden. This is because only small amounts of coke were available and even those were regarded as nuisance rather than an asset to the blast furnace operations.

Oliphant and probably many other blast furnace men of that time were happy about being able to dispose of it in the blast furnace without decidedly unfavorable results. In 1835, Oliphant smelted a small amount of iron exclusively with coke. The coke iron and the raw materials used in its produc-





The contour lines of modern coke furnaces, showing the gradual increase in height and diameter. With furnaces such as these, U. S. pig iron production soared while the total number of operating furnaces decreased.

tion were sent to the Franklin Institute in Philadelphia where they were exhibited for a number of years.

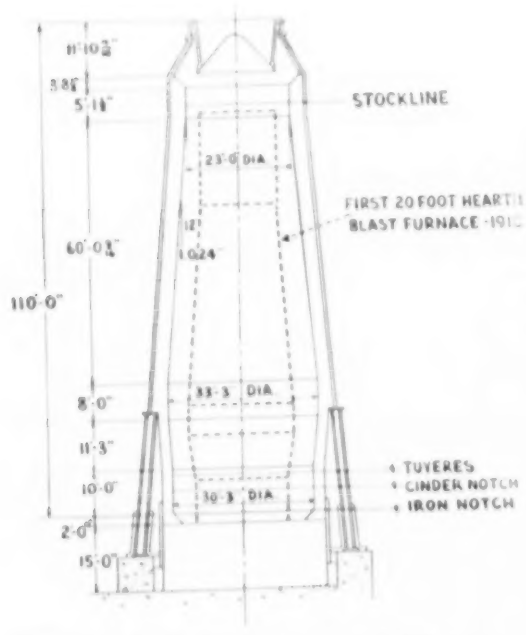
The Oliphant Furnace was, however, not the first one to attempt production of coke iron on a commercial scale. The Lucy-Salina furnace of the Longdale Iron Company of Longdale County, Pennsylvania is reported to have been burdened with coke in 1828. The furnace was originally built in 1827 for exclusive use of charcoal. Gradually, however, small amounts of coke of uncertain origin were being added for trial purposes only. The original cold blast furnace was converted to a hot blast unit in 1842 or 1843 and gradually amounts up to 50 pct of coke fuel were being added. The furnace, which was rebuilt again in 1873 to 11 ft bosh diam and 44 ft height, operated after that time exclusively on coke.

The first major attempt to use 100 pct coke burden was made by William Firmstone at the Mary Ann Furnace in Huntington County, Pennsylvania in the spring of 1835. It was followed closely by the experiment of Frank Oliphant who also reported similar results.

During 1835, 1836, and 1837 blast furnaces were built at Carthouse and Ferrandsville on the west branch of the Susquehanna River and at Frozen Run near the Lycoming River. The Carthaus furnace produced several hundred tons of iron which, partly because of its high sulfur content and partly because of the superstitions of the old foundry men, proved unsoluble. The furnace was subsequently converted to charcoal.

The furnace at Ferrandsville was unfavorably placed in regard to the iron ore, which had to be brought over distances of 20 to 100 miles. The coke which was considered for this installation proved also to be of extremely poor quality, since it tended to "plug up the furnace and make it run cold". This was because the coals available were of poor coking characteristics and did not produce strong, hard coke. It appears that the coal in question was splint coal mined in the Ferrandsville area. The operations of this blast furnace were terminated in 1840 or 1841. The Ferrandsville plant practice, however, indicated clearly that the coke was being made from coal. This appears to be one of the first commercial coking operations in the United States.

No better was the fate of the Frozen Run Furnace which, though located near the ore body, suffered under extremely poorly coking coals.



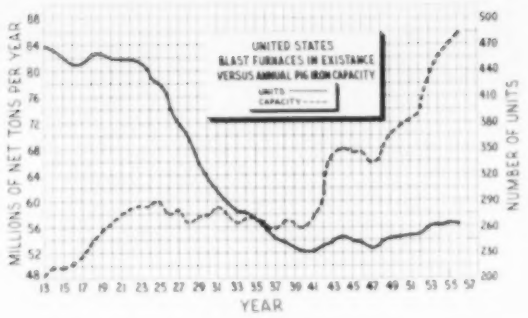
Comparison of the contour lines between a 1918 furnace with 20 ft hearth, and blast furnace A of Great Lakes Steel Corp. at Zug Island.

Tonnage spirals upward

Significant progress in the American iron industry began in 1880. The Struthers furnace of Ohio was one of the first which became famous for the amounts of iron it produced. It was 54 ft-9-½ in. high, had a diameter of 16 ft at the bosh, 9 ft 1-½ in. in the hearth. The fuel was raw coal (semi-anthracite). This furnace made 1627 tons of iron in December, 1871, and 1668 tons of iron in January, 1872. The best production week was 406 tons. In March of 1872 the production increased to 2064 tons.

There is a report about the Isabella furnace #1 near Pittsburgh, which was also famous in the iron industry. The dimensions were: height—75 ft, the bosh diameter 20 ft, and the capacity 15,007 cu ft. The furnace was in operation from January 1876 until May 1880 and made a total of 119,486 tons or an equivalent of 2,300 tons per month, with a consumption of 3153 lb of coke, blast temperature of 540 to 590°F and 0.6 to 0.9 lb pressure. The Lucy Furnaces of the Carnegie Phipps & Co. were also outstanding in their production. The dimensions of the furnace were: total height 75 ft, 20 ft at the bosh and 9 ft ¼ in. at the hearth, and total volume 15,395 cu ft. Mr. Curey who was the manager of the plant stated to Mr. Gayley that the contour lines were largely responsible for the excellent results obtained on this furnace which produced on the average 3338 tons per month in 1878 with a coke rate of 2749 lb per ton and made shortly thereafter 834 tons of iron in one week. The furnace was blown in September of 1877 but was shut down again shortly because of difficulties in the construction.

The blast furnace *A* of the Edgar Thomson Works was originally a charcoal blast furnace at Escanaba, Michigan. It was dismantled there and brought to the Thomson Works in 1879 and reconstructed. The dimensions were as follows: height 64 ft 11½ in., bosh diameter 12 ft-11⅞ in. hearth 8½ ft. The furnace operated with six tuyeres located at 5½ ft above the bottom of the hearth and measured 3-15/16 in. diam. The average ore burden to the furnace contained 54.5 pct iron. In March of 1880 this furnace produced 2806 tons of iron, with a coke rate of 2269 lb per ton. The blast volume was set at 15,007 cfm. which was almost double the average volume used on most American blast furnaces of the day. The experiences obtained with the *A* blast furnace at the Edgar Thomson Works were incorporated in the design of the second blast furnace whose dimensions were: height 79 ft 11-⅞ in., bosh diam 20 ft, hearth diam 10 ft-11-⅞ in., volume 17,867 cu ft. The selection of the hearth diameter was based on the results obtained by the Crane Iron Company in the Lehigh Valley, who was regarded as a top producer of iron. The production data show that from May of 1880, when the furnace produced 3777 tons at a coke rate of 2535 lb, the production increas-



ed to 4798 tons per month in October of the same year with a coke rate of 2692 lbs. Another blast furnace was built in 1885-86 at the Thomson Works. The height and hearth diameter of previous blast furnaces was retained, but the diameter of the bosh was increased to 23 ft. The bell measured 12 ft. The total working volume was 19,774 cu ft. The furnace was put into operation in October 1886 and produced gradually increasing amounts of iron: in November of 1886, 6843 tons, 1874 lb of coke per ton, December, 7614 tons at 2072 lb of coke, and January, 1887, 8532 tons at a coke rate of 1905 lbs.

If production figures seemed high in the 1800's, they certainly outstripped all expectations by the 1900's. At this time a very significant change in the basic blast furnace design occurred when the height of the bosh was lowered from 20 ft to 12 ft on the Edgar Thomson *D* furnace. Because of the success of this radical change, it has remained with us today. The furnace was capable of averaging about 463.4 tons per day with a coke rate of 2227 lb per ton. According to George E. Rose, "Legend seems to ascribe this pulling down of the hearth of the mantle making the lower bosh possible to Pig Iron-Jim Gayley."

The next improvement was the increasing of hearth diameter. Certainly one of the factors involving this change was a natural reluctance on the part of blast furnace designers to develop a non-penetration area at the tuyere zone. Gradually this reluctance was overcome as success in the form of greater production followed the increased hearth diameter. Possibly this non-penetration was avoided, at least in part, because maintaining the almost universally successful 12 ft high bosh at the same time gradually increasing hearth diameter naturally resulted in a similar gradual increase of the steepening of the bosh angle. For example in 1905, the bosh angle was 76° and by 1927, South Works No. 7 furnace had a bosh angle of 80° 33′. The average daily output for this furnace in 1929 was 679.6 tons with an average coke practice of 1839 lbs.

Hearth diameters continued to increase, but when 18 ft 9 in was no longer enough, 22 ft hearth diameters became necessary. The point at which the 22 ft bosh diameter had to retreat was when the gradually increasing hearth diameter itself finally reached 22 ft. Then, in order to have a bosh at all, the bosh diameter had to be increased to 26 ft. Departure from this tradition took place at Gary No. 9 in 1927. The average daily production was 880 tons with a coke rate of 1845 pounds. The total production for three years was 939,000 tons.

Although the era of the new big 1000 tpd furnace was initiated by the Ohio Works No. 2 in 1929, it was not until the first depression years that several others began to be built. Inland's No. 5 was built in

Pig Iron Production Capacities by Furnaces and Districts in the U. S. A., 1955

District	No. of Furnaces		Total Annual Capacity, Net Tons
Eastern	54	(a)	17,690,000
Pittsburgh-Youngstown	95	(b)	30,495,350
Cleveland-Detroit	25		10,001,700
Chicago	48		16,830,500
Southern	12	(c)	6,427,080
Western	12		4,040,600
Total	261	(d)	85,485,230

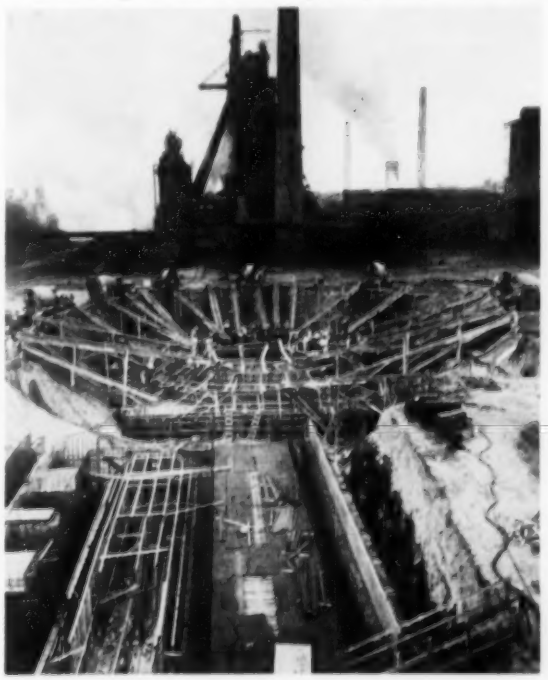
(a) Includes 384,000 tons ferro-alloys capacity.
(b) Includes 322,800 tons ferro-alloys capacity.
(c) Includes 103,000 tons ferro-alloys capacity.
(d) Includes 809,800 tons ferro-alloys capacity.

Blast Furnace Dimensions

	Great Lakes *A*	Haven's 1940 Prediction
Hearth Diam	30 ft-3 in.	30 ft
Bosh Diam	33 ft-3 in.	32 ft-9 in.
Stockline Diam	23 ft	21 ft-6 in.
Bell Diam	16 ft-6 in.	16 ft

1937 with a bosh and hearth diameter of 28 ft and 25 ft respectively, similar to Ohio Works' No. 2 of 1929. Choice of these dimensions undoubtedly was influenced by the *ideal* blast furnace profile recommended by the Blast Furnace & Coke Association of the Chicago District, whose findings were published about that time

Furnaces continued to grow in size and their auxiliary equipment in proportion, but since the breakaway from the 22 ft bosh, no significant new structural changes were made. Great Lakes *A* Furnace at Zug Island was completely rebuilt in 1934



Laying of the foundation for Kaiser Steel's fourth blast furnace at Fontana, Calif. Scheduled for operation early in 1958, the furnace is expected to push Kaiser's output close to the goal of 3 million tons a year.

and represents the giant or size. Hearth diameter is 30 ft 3 in., bosh diameter 33 ft 3 in. The total working volume is almost 65,000 cu. ft.*

* Since this writing, two larger furnaces have been built in England, both having a hearth diameter of 31 ft.

William A. Haven predicted dimensions for a 30 ft furnace approximately 15 years before the furnace was constructed. The furnace had 24 tuyeres and a blowing engine capable of 125,000 cfm at 35 psi.

No history of blast furnaces in the United States would be complete without a mention of the recent westward development. Henry Kaiser's plant, built in 1942, was the first successful unit to operate on the west coast. Certainly the existence of the war hastened this move. *Bess* was blown in on December 31, 1942 and produced 2,012,266 tons on her first 5-½ year campaign. Today three 25½ ft furnaces are successfully operating at this site, with a fourth under construction.

Perhaps another result of World War II was the introduction of high pressure at the furnace tops. The first furnace where this technique was used was the D.P.D. No. 5 furnace at Republic Steel Corporation in Cleveland, Ohio. The inventor was Julian M. Avery. At this writing, there are 28 furnaces installed with high pressure tops. Some controversy exists over the ideal top pressure, however, 7 psi top pressure seems to be the accepted figure .

One of the most interesting facts to come to light in a study of history of blast furnaces is not so much the simple growth of the structure itself as the increase in tonnages figures, all out of proportion to actual increase in size unit-wise.

From 1810 to 1898, the total annual pig iron production increased from 60,377 net tons to 13,186,806. Today there are 60 pct fewer blast furnaces than fifty years ago, but technical progress in blast furnace construction and operation has increased the total blast furnace capacity of the country from 12 million to about 84 million net tons.

In the past, tonnage capacity was increased by adding units and by increasing the size of units. As demand for iron increased, construction costs have soared, so that now every effort is being brought to bear on the greatest possible utilization of the present equipment along with every technological improvement in handling or processing raw materials.

Bibliography

[1] Lawthian Bell: *Principles of the Manufacture of Iron and Steel*. 1884. London.
[2] Charles S. Boyer: *Early Forges and Furnaces in New Jersey*. 1931. Philadelphia. University of Pennsylvania Press.
[3] H. M. Boylston: *Metallurgy of Iron and Steel*. 1928.
[4] A. P. Bruce: *Economic History of Virginia in the Seventeenth Century*. 1918. vol. 2. New York. MacMillan Co.
[5] Kathleen Bruce: *Virginia Iron Manufacture in the Slave Era*. 1931. New York.
[6] Z. W. Coombs: *Early Blast Furnace Operations*. 1929. Worchester.
[7] 1901. Berlin.
[8] E. F. Durre: *Blast Furnace Plant at the End of the XIX Century*. 1901. Berlin.
[9] William Durfee: *The Development of American Industries Since Columbus*. Popular Science Monthly, December 1890.
[10] Francis Firmstone: *Development of the Size and Profile of the Blast Furnaces in the Lehigh Valley*. *Iron Trade Review*, 1909, pp. 745-750.
[11] William Firmstone: Sketch of Early Anthracite Furnaces. *AIME Trans.*, 1874, vol. 3.
[12] J. Gayley: Development of the American Blast Furnace Process. *Stahl und Eisen*, 1899, vol. 10, p. 1004.
[13] F. L. Grammer: A Decade in American Blast Furnace Practice. *AIME Trans.*, 1905, vol. 35, pp. 117-123.
[14] Albert D. Hager: *Report on the Geology of Vermont*. 1861.
[15] E. N. Hartley: Iron, Steel, and American History. *AISI*, Regional Meetings, 1953.
[16] G. Jars: *Metallurgical Travels*. 1777-1785, vol. I. Berlin.
[17] E. C. May: *Principia to Wheeling*. 1945. New York. Harper Brothers.
[18] Fredrick Overman: *The Manufacture of Iron in All Its Various Branches*. 1854.
[19] John Percy: *Metallurgy of Iron and Steel*. 1864. London.
[20] Richard Peters, Jr.: *Two Centuries of Iron Smelting in Pennsylvania*.
[21] E. C. Potter: *Journal*, Iron and Steel Institute, 1887, pp. 437-442.
[22] E. Roberts: Anthracite Blast Furnaces. *Iron & Coal Trades Review*, 1910, p. 767.
[23] J. M. Swank: *History of the Manufacture of Iron in All Ages and Particularly in the United States*. 1884. Philadelphia.
[24] J. Swank: Early Iron Enterprises in Pennsylvania. *American Manufacturer and Iron World*, November 1900.
[25] R. H. Sweetser: *Blast Furnace Practice*. 1938.
[26] R. H. Sweetser: Blast Furnace Fuels—Anthracite Coal. *AIME Trans.*, 1935, vol. 116.
[27] Samuel Thomas: Reminisces of the Early Anthracite Iron Industry. *AIME Trans.*, 1899, vol. 29.
[28] Thomas Turner: *The Metallurgy of Iron*. 1905, Ed. by Sir Roberts-Austen. London.
[29] Clyde Williams: Production of Sponge Iron. 1927. U. S. Bureau of Mines. *Bulletin* No. 270.
[30] C. H. J. Woodbury: *History of Lynn, Mass*. 1844. Lewis.
[31] *Directory of the Iron and Steel Works*, 1873 and 1874, vol. I and II, respectively.
[32] New Blast Furnace in America. *Stahl und Eisen*, 1900, vol. 20, pp. 52-53; also *Iron Age*, October 1900, pp. 1-3.
[33] Renton Patent Furnace. *Scientific American*, 1854.
[34] Development of the Iron Industry in U.S.A. *Carrier Magazine*, 1900, pp. 459-471; also *Iron Age*, March 1900, p. 3.
[35] The Modern Blast Furnace and Auxiliaries, *Blast Furnace and Coke Association of the Chicago District*, 1930.
[36] T. J. Ess: The Modern Blast Furnace. *Iron and Steel Engineer*, 1946.
[37] Charles P. Betz and Owen R. Rice: *The World's Largest Blast Furnace*. Paper presented November, 1954, Joint Meeting of the Blast Furnace and Coke Association of Chicago District and the Eastern States Blast Furnace and Coke Association.
[38] *AISI*, Compilations, January, 1956.
[39] John Fritz: The Development of Iron Manufacturing in the United States. *Cassiers Magazine*, November 1899-1900.

Electrolytic Preparation of Thorium Metal

Thorium chloride dissolved in molten sodium chloride can be electrolyzed in a continuous process for the production of granular, high purity thorium metal powder. The preparation of anhydrous chloride, its electrolysis in an expanded scale cell, and the purity and some mechanical properties of the product thorium are described.

by B. C. Raynes, J. C. Bleiweiss, M. E. Sibert, and M. A. Steinberg

IN the early part of 1952, under the auspices of the U. S. Atomic Energy Commission, Horizons Inc. undertook an investigation dealing with the preparation of high purity thorium metal in order to develop an economically competitive production process for this metal based on a recovery of the metal by a fused salt electrolysis, since a survey of the literature of thorium chemistry indicated that electrolytic methods had not received much attention, despite the consideration that electrochemical production methods often offer attractive commercial potentialities.

Thorium metal has been prepared by methods which fall into four general categories: 1) reduction of halides or double halides; 2) reduction of the oxide; 3) thermal decomposition of halides; and 4) electrolytic methods.

Some of the important results obtained by various investigators since about 1900 in recorded attempts to prepare pure thorium metal are summarized in Table I. A bibliography of pertinent literature is included in this paper.

Thorium is strongly electropositive and possesses a great affinity for oxygen and nitrogen. As a result the prospects for the production of high purity thorium from aqueous media or oxygen bearing compounds are remote. The most promising and profitable area of investigation for production of thorium metal lies in fused salt electrolysis. Thorium has been produced previously by this technique from halide salts in fused alkali chloride eutectic mixtures. Until recently, however, the lack of known large uses for thorium has inhibited the investigation of these methods.

The basic problem in an investigation into fused salt production methods for thorium is to develop a suitable fused salt system for the economic preparation of thorium. The first portion of the work in these laboratories was a small scale investigation of the electrolysis of potassium thorium fluoride, $KThF_5$, under a variety of conditions. High purity thorium was prepared in this manner, but the process did not appear to offer the simplest and most attractive continuous commercial operation.

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TP 4576D. Manuscript, Apr. 5, 1956. New York Meeting, February 1956.

The work reported here relates to an all-chloride system employing thorium chloride as the cell feed. $ThCl_4$ was produced as an anhydrous material stabilized in molten sodium chloride. This product, further diluted in NaCl, was subjected to electrolysis. The electrolytic process has been studied in cells capable of holding up to 50 lb total salt charge. Ductile, pure thorium metal has been reproducibly obtained in this operation. Considerable experimentation was carried out in the preparation of $ThCl_4$ as a cell feed free from moisture, oxides, and other impurities.

Thorium was cathodically deposited as a coarsely crystalline powder interspersed with residual bath salts. Aqueous procedures for separating and recovering the metal were developed.

The thorium metal powder obtained has been evaluated with respect to its hardness, chemical purity, and certain other physical properties.

Preparation of $ThCl_4$.—Thorium chloride, and the chlorides of some other metals (aluminum, beryllium, tantalum, zirconium, etc.) cannot be obtained from aqueous solution by direct heating and evaporation. Evaporation and heating of a solution of thorium chloride yields a hydrated salt or partially hydrated salt, and finally ThO_2. Anhydrous thorium chloride is obtained by forming a hydrated ammonium chloride complex salt in acidified water solution, dehydrating this compound, and finally decomposing the double salt and subliming the ammonium chloride component.

Various methods for the preparation of anhydrous thorium chloride, in accordance with this concept, were investigated as indicated in Table II from hydrated thorium chloride ($ThCl_4 \cdot 3H_2O$), and from thorium oxycarbonate ($ThOCO_3$). In the method found most satisfactory for this work, thorium oxycarbonate was dissolved in an excess of concentrated HCl to give a clear yellow solution. At least 2 mol NH_4Cl were added to the solution per mol of contained thorium. Ammonium thorium chloride hydrate was crystallized from solution by cooling and saturation with HCl. The resultant complex, $(NH_4Cl)_2ThCl_4 \cdot xH_2O$, was dehydrated by evaporation at 130° to 150°C and thoroughly dried at about 250°C. The dried ammonium thorium chloride was then mixed with sodium chloride in proportions to form $NaThCl_5$ or to produce a $ThCl_4$-NaCl mixture with a given thorium content. The ammonium chloride was sublimed off at temperatures above 500°C in an inert atmosphere furnace to give an anhydrous chloride source electrolyte, essentially free of ThO_2 and of NH_4Cl.

The Transactions papers appearing in JOURNAL OF METALS *during 1957 will subsequently appear in AIME Transactions Volume* 209, *and may be permanently referenced to that volume.*

Table III presents analyses of typical $ThCl_4$-NaCl cell source electrolytes to indicate the quality of the essentially anhydrous material which can be produced by the method described.

Thorium chloride thus produced was determined to have a decomposition potential of 2.2 volts at 800°C. The determined variation of this value with temperature is shown in Fig. 1. (For comparison, the curve for ThF, is also given.)

The all-chloride source electrolyte prepared as described, or by slight modifications of that procedure, was the material with which the majority of the electrolytic work was done. The process was amenable to continuous operation and represents the goal of the investigation for a source electrolyte.

Small Scale Operation—A series of runs was first made in small laboratory cells available at these laboratories. These cells have been described in detail elsewhere.[8] From this work, the following operating parameters were found to apply to the electrolysis of $ThCl_4$ in NaCl to produce granular, high quality thorium metal:

1) In order to produce thorium metal of high quality (Rв 30 or lower in hardness) the thorium chloride source electrolyte must be anhydrous and contain less than 0.1 pct of insolubles.

2) The electrolytic cell atmosphere must be inert and free from oxygen, water vapor, or nitrogen.

3) The fused solvent, NaCl, must be anhydrous and free from insolubles.

4) The optimum operating temperature range for electrolysis is between 780° and 850°C.

5) The cathode temperature must be maintained at no more than 850°C during operation, either by cooling or by control of current passage.

6) Cathode current density and thorium concentration are mutually dependent. In general, product crystal size increases with higher thorium ion concentration and lower current densities. Some low process efficiencies observed at the low thorium ion concentration (2 to 8 pct Th ion) are believed to have been the result of the loss of some of the fine metal particles produced in these circumstances in the product aqueous recovery procedure. The optimum thorium ion concentration range was determined to be 10 to 15 pct; cathode current densities optimum for this range of thorium ion concentration is 300 to 400 amp per sq dm.

7) The system $ThCl_4$-NaCl is capable of being operated continuously by adding make-up cell feed containing additional thorium ion. These make-up salts can be added during an electrolysis, or preferably following a cathode withdrawal.

Intermediate Scale Operation—Once operating conditions for the $ThCl_4$-NaCl fused salt system had been established in the laboratory cell, the scale of operation was expanded approximately tenfold. The laboratory work was performed in a cell whose crucible was 4 in. ID and which operated with about a 6-in. deep fused salt bath. The intermediate scale of operation discussed in this section was performed in a cell whose crucible was 8½ in. ID and which operated with a 10 to 12 in. bath depth. A total of 50 lb of molten salt could be accommodated in this crucible.

In its construction, the intermediate scale electrolytic cell was substantially the same as the small scale laboratory cell. The crucible was a monolithic, machined shape of graphite, which served as the anode. The crucible was surrounded by a single-phase graphite resistor which consisted of graphite links and rods. The shell of the cell was circular in cross section, all nickel, and insulated with *K*-28 fire brick. The upper section of the shell was flanged; the lower portion was welded to a solid nickel plate. The anode connection to the crucible was made from this bottom plate by three graphite

Table I. Thorium Metal Production Processes

Thorium Halide	Reducing Agent	Product	Reference
	Reduction of Halides or Double Halides		
$ThCl_4$	Na or K	Th powder	Berzelius[1]
$KThCl_5$	Na or K under H_2 atm	Th powder	Chauvenet[2]
NH_4ThCl_5	Al	Alloy—Al distilled or acid (HNO_3) removed	Marden[17]
$KThF_5$	Al in electric arc furnace under vacuo or inert atmosphere	Ingot	Marden[16]
$NaThCl_5$	K vapor obtained from KCl and CaC_2 reaction	Th powder	Lautie[32]
$ThCl_4$ (70 pct) in $ThOCl_2$ (30 pct)	Ca	Th powder	Westinghouse[20]
$ThCl_4$	Mg	Th powder	Ames Lab
ThF_4	Ca-$ZnCl_2$ booster	Zn-Th alloy biscuit (sponge)	Ames Lab and National Lead Co., Fernald Plant
$ThCl_4$ or $ThOCl_2$	Ca	Th powder	Lilliendahl[18]
	Reduction of the Oxide		
Thorium Source			
ThO_2	Mg	Th powder	Winkler[30]
ThO_2	Si	Th powder	Honigschmidt[9]
ThO_2	Al and C	Th powder	Moissan and Etard[26, 27]
ThO_2	Ca with $CaCl_2$ under argon at 1400°C	Th powder	Huppertz,[3] Kuzel and Wedekind[12]
ThO_2	Na with $BaCl_2$		Cachiemaille[5, 6]
ThO_2	CaH_2	Th powder	Metal Hydrides
ThO_2	H_2 + N_2 at 2500°C	?	Von Wartenburg et al.[29]
ThO_2	C + H_2 at 1000°C	?	Schlect and Jahrstoffer[28]
ThO_2	Ca	Th powder	Rentschler et al.[24]
	Thermal Decomposition of Halides		
	Apparatus		
ThI_4	Hot wire technique	Crystal bar	Van Arkel[27]
	Electrolytic Methods, Aqueous and Organic		
	Electrolyte		
$Th(OH)_4$	HBF_4	?	Marden et al.[16]
Thorium salts	HSO_3NH_2	?	Piontelli and Buillotto[23]
Thorium salts	C_2H_5OH; CH_3OH; C_5H_5N; other alcohols	Thorium organic composition	Atanasin and Babor[1]
Complex thorium salts	Organic acids	?	Kuizumi[15]
$Th(NO_3)_4$	C_2H_5OH with 15-20 pct Me_2CO	ThO_2	Cotelli and Haissinsky[4]
	Electrolytic Methods, Fused Salts		
$ThCl_4$	KCl-NaCl	Th with ThO_2 + C	Moissan and Honigschmidt[22]
$KThF_5$	NaCl-KCl	Th powder	Driggs and Lilliendahl[7] Marden[16]
$ThCl_4$	NaCl and KCl-NaCl	Th powder	Horizons Inc.
$KThF_5$	NaCl	Th powder	Horizons Inc.
ThF_4	NaCl-KCl	Th powder or Th in liquid Zn cathode	Horizons Inc. Kaplan[10, 11] Geneva Conference

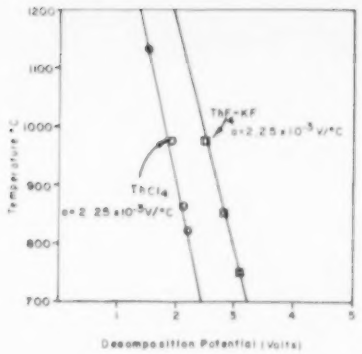

Fig. 1—Decomposition potential relation with temperature for thorium salts in NaCl.

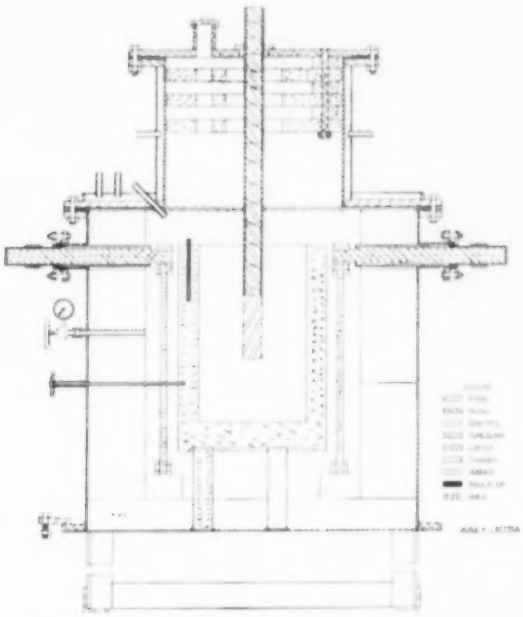

Fig. 2—Assembly drawing of intermediate scale electrolytic cell.

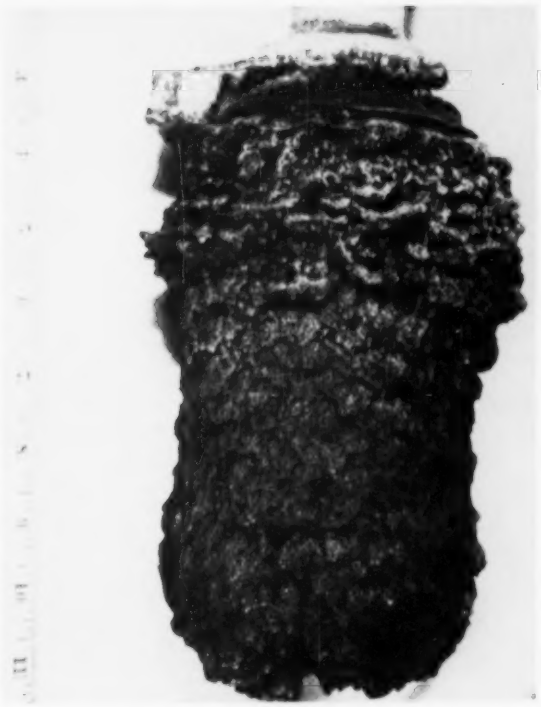

Fig. 3—Typical cathode deposit from intermediate size cell; approximately 5 lb of thorium metal plus occluded bath salts.

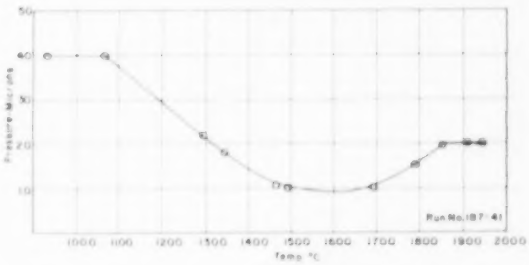

Fig. 4—Temperature-pressure curve for thorium melted in vacuum-induction furnace.

posts which supported the crucible. In operation, the entire shell of the cell was anodic.

The cell was provided with an upper, water-cooled assembly and operating head. The operating head was provided with heat reflector shields, an insulated port for a cathode, and a port for salt addition and chlorine evolution. An assembly drawing of this cell is shown in Fig. 2.

The cell was provided with a dc source capable of delivering 1000 amp at 12 volts, a 32 kw ac source capable of delivering 600 amp, an argon metering system, and a ventilating hood. The cell

Table II. Methods for Preparation of Thorium Chloride Cell Feed Mixtures

Method	Temperature, °F	Time, Hr	Overall Reaction	Remarks
1	600	4	$ThCl_4 \cdot 3H_2O + NaCl + 3NH_4Cl \rightarrow NaThCl_5 + 3NH_4OH + 3HCl$	$ThCl_4 \cdot 3H_2O$ was dried prior to reaction.
1	200	To dryness	$ThCl_4 \cdot 3H_2O + NaCl + 3NH_4Cl \rightarrow NaThCl_5 + 3NH_4OH + 3HCl$	Yellow-tinted product. Heated in graphite crucibles.
1	600	16	$ThCl_4 \cdot 3H_2O + NaCl + 3NH_4Cl \rightarrow NaThCl_5 + 3NH_4OH + 3HCl$	White product. Heated in graphite.
2	600	16	$ThOCO_3 + 4NH_4Cl + NaCl \rightarrow NaThCl_5 + 4NH_3 + 2H_2O + CO_2$	
3	600	4	$ThOCO_3 + NaCl + 6NH_4Cl \rightarrow NaThCl_5 + CO_2 + 6NH_3 + 2H_2O + 2HCl$	Micropulverized before heating in graphite crucibles.
4	300	2	$ThOCO_3 + 3HCl + NaCl + NH_4Cl \rightarrow$	HCl solution evaporated to dryness prior to heating in graphite crucibles. Gray color.
	600	14	$NaThCl_5 + CO_2 + NH_3 + 2H_2O$	
5	300	2	$ThOCO_3 + 10HCl + 3NH_4Cl + 2NaCl \rightarrow$	Heated in air. Top crust high in ThO_2. Bottom was fused mass containing 90 pct $ThCl_4$, 0.29 pct ThO_2.
	900	20	Anhydrous HCl to saturation $\rightarrow$ $(NH_4Cl)_2ThCl_6 \cdot xH_2O$ + etc.	
5	300	17	$ThOCO_3 + 10HCl + 3NH_4Cl + 2NaCl \rightarrow$	Heated in air. Top crust, 5 pct of total, was high in ThO_2. Remainder contained 85 pct $ThCl_4$, 15 pct NH_4Cl, no ThO_2.
	650	69	Anhydrous HCl to saturation $\rightarrow$ $(NH_4Cl)_2ThCl_6 \cdot xH_2O$ + etc.	
5	300	37	$ThOCO_3 + 10HCl + 3NH_4Cl + 2NaCl \rightarrow$	Exposed to air when heated; contained 1.8 pct ThO_2.
	650	100	Anhydrous HCl to saturation $\rightarrow$	
	1000	50	$(NH_4Cl)_2ThCl_6 \cdot xH_2O$ + etc.	

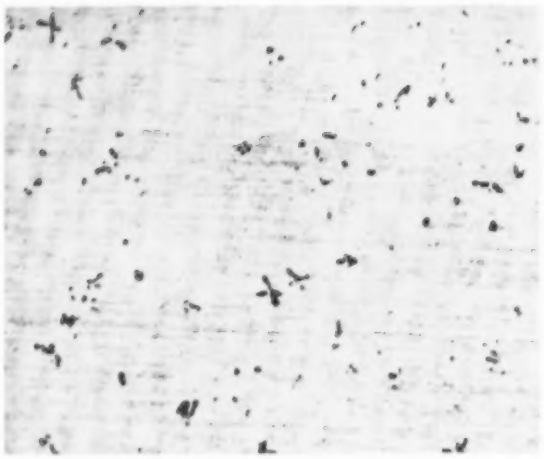

Fig. 5—Structure of arc-melted thorium electrolytically produced from ThCl$_4$-NaCl. Oxide phase present. Hardness of Rb 11. Unetched. X250. Reduced approximately 25 pct for reproduction.

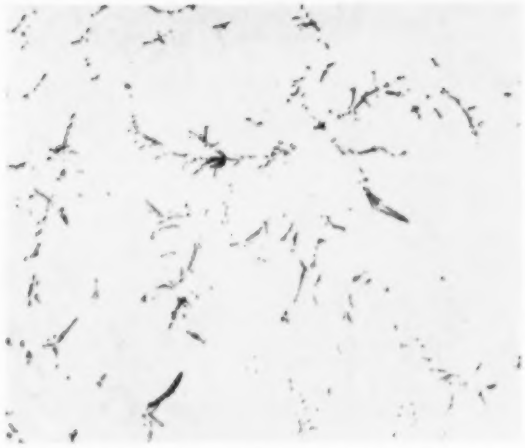

Fig. 6—Structure of arc-melted electrolytic thorium from ThCl$_4$-NaCl with the oxide phase in a dendritic pattern. Hardness of Rb 36. Etched. X250. Reduced approximately 25 pct for reproduction.

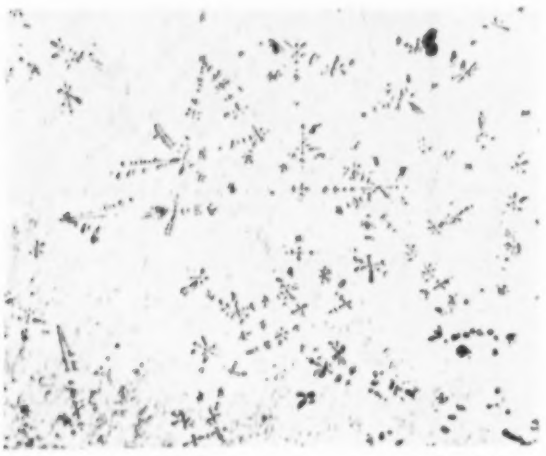

Fig. 7—Arc-melted thorium (electrolysis of ThCl$_4$-NaCl) showing a dendritic pattern of oxide. Hardness of Rb 53. Unetched. X250. Reduced approximately 25 pct for reproduction.

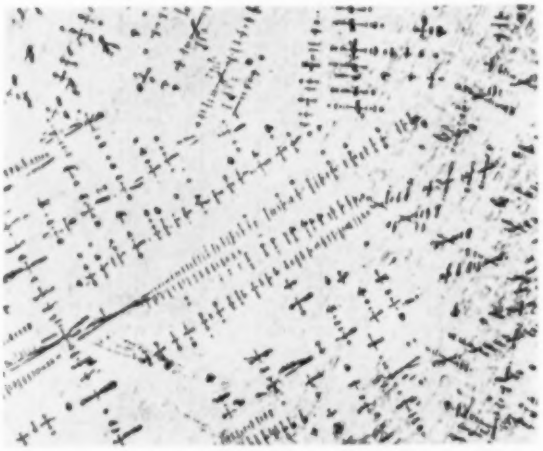

Fig. 8—Arc-melted electrolytic thorium; microstructure from the highest hardness range showing large amount of oxide. Hardness of Rb 70. Unetched. X250. Reduced approximately 25 pct for reproduction.

was both gas and vacuum-tight.

The cathode for this cell consisted of a steel or Hastelloy C cylinder, 1½ in. in diam and 5 in. long, welded to a 1¼ in. diam nickel rod. A graphite sleeve protected the nickel rod against chlorine attack and extended through the operating head. The cathode connection from the dc source was made directly to the nickel rod. A nonconducting bushing insulated the cathode from the operating head. The anode connection was from the bus bar to a steel boss welded to the bottom plate of the cell.

This cell was ordinarily operated as a batch unit. A crucible was placed in the cell, upon the anode posts, and charged with cell feed and additional sodium chloride to achieve the desired thorium ion concentration. The operating head was cleaned, positioned, and bolted down. The vacuum flange was bolted to the head and the cell evacuated and flushed with argon several times. When an inert (argon) atmosphere had been established, the vacuum flange was removed, an argon flow was started, and heating of the cell charge begun. The salts were melted in about 1½ to 2 hr.

After the salts were molten and the bath was at the chosen operating temperature, the cathode was inserted into the bath under a polarizing voltage of about 2.5 volts dc. When the cathode reached bath temperature (about 5 min), the voltage was increased and electrolysis initiated. After completion of electrolysis, the cathode was again polarized and withdrawn from the bath but held in the inert atmosphere of the cell. The entire cell was cooled under an argon atmosphere overnight. Before the subsequent run, the operating head was removed, the cathode withdrawn, the crucible either removed or recharged, and the unit reassembled.

Once the operation of this electrolytic cell was established and routine, no inherent difficulties were encountered in the process scale-up. Table IV presents representative electrolytic results obtained in operation of this intermediate scale cell. A typical cathode deposit, containing over 5 lb of thorium metal, produced in this cell is shown in Fig. 3.

Fig. 9—Structure of as-cast electrolytic thorium cold rolled to 90 pct reduction. Initial hardness of Rb 15. Lightly etched. X100. Reduced approximately 25 pct for reproduction.

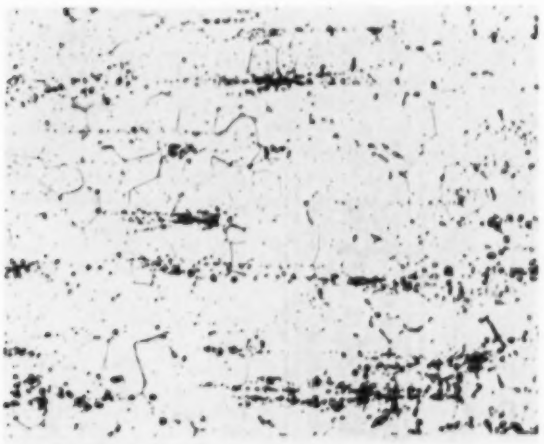

Fig. 10—As-cast electrolytic thorium recrystallized at 1000°C for 30 min after cold rolling to 90 pct reduction. Etched. X100. Reduced approximately 25 pct for reproduction.

Those operating parameters defined in the small cell scale of operation were proved to determine the operation in this intermediate scale of operation. This ease of scale-up indicates that further expansion of scale is clearly practicable.

Evaluation and Properties of Electrolytic Thorium Metal

Product evaluation was determined by hardness and ductility studies on the arc cast metal and by chemical analysis. For hardness and ductility studies, the electrolytically produced, granular thorium was consolidated by pressing into dense compacts 1 or 1¼ in. in diam and ¼ to ⅜ in. in height and arc melting these compacts in a conventional tungsten arc, water-cooled copper-hearth furnace under argon. Electrolytic thorium metal has exhibited hardnesses in the as-cast state as low as RB5 (Vhn 68). From a consideration of the many runs made on this process, it is believed that a fair statement of the expected average hardness of thorium metal produced by the electrolysis of thorium chloride is Vhn 70 to 80. Thorium metal with as-cast hardness well above these values has been made during the present work. In each case, however, it was found that operation outside of the established process parameters was involved. Source electrolyte material of low purity, failure of some electrolytic cell component, or contamination of product by improper metal recovery procedures can result in a product metal not within these purity and hardness specifications. Under controlled operating conditions the electrolytic process described in this paper is capable of producing high quality, low hardness thorium metal reproducibly.

Table V gives typical spectrographic analyses of thorium produced as powder, arc-melted pellets, and rolled strip. Carbon and insoluble contents are also given.

Induction Melting—Some electrolytic thorium was induction-melted in beryllia crucibles to determine melting characteristics of this type of thorium. It was subsequently canned in a steel container and hot rolled directly followed by cold rolling.

Thorium powder of 1½ lb was cold-pressed at 20 tsi in a 1½ in. steel die to form completed briquets. These briquets were charged to a previously baked-out beryllia crucible and heated in vacuo by induction to the melting point of thorium. The ingot was allowed to solidify and cool to room temperature in the vacuum furnace.

Fig. 4 shows the pressure, in μ, as a function of temperature from 1000°C through the melting point. As can be seen from the figure, the rather high pressure in the temperature range of 1000° to 1400°C is probably due to the sublimation of residual salts not completely removed in the metal recovery step and to dissolved gases. Above 1500°C the pressure decreases to about the ultimate rating of the system employed. There is a slight increase in pressure at temperatures above the melting point of the thorium metal.

Tensile Properties—Two tensile specimens were prepared and tested to fracture. The sheet was rolled from the small ingot of thorium which was induction-melted in a beryllia crucible under vacuum. The ingot was sealed in a steel jacket and hot rolled to a thickness of ⅛ in. (a reduction of about 50 pct). This sheet was then cold rolled to 0.040 in. thickness for the tensile tests. The specimens were vacuum annealed at 600°C for 1 hr prior to testing. The average values of ultimate strength, yield point (0.2 pct), and percentage of elongation in a 1-in. gage length were as follows: 52,235 psi ultimate tensile strength, 41,675 psi yield point, and 11.2 pct percentage of elongation.

Microstructures—An attempt was made to relate the microstructures of arc-melted thorium pellets with hardness and chemical composition. A series of arc-melted thorium pellets ranging in hardness from RB 11 to RB 70 were examined metallographically for evidences of microstructural differences. The results of these observations are recorded in Table VI and in the micrographs in Figs. 5 to 8.

A general trend was evident in that a larger amount of precipitate phase occurred as specimen hardness increased. Thus, the specimen shown in Fig. 5, which had a hardness of RB 11, shows randomly distributed gray particles of indefinite pattern. On the other hand, the specimen microstructure in Fig. 8(RB 70) shows a large amount of the gray phase in a dendritic pattern.

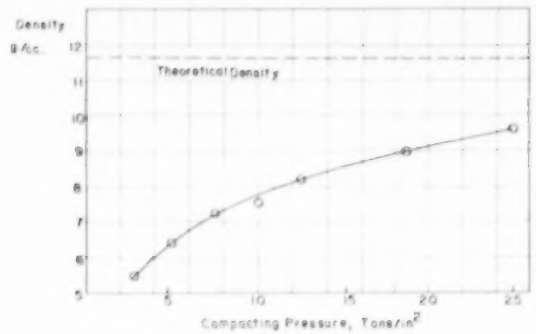

Fig. 11—Relation of green density to cold compacting pressure for electrolytic thorium powder.

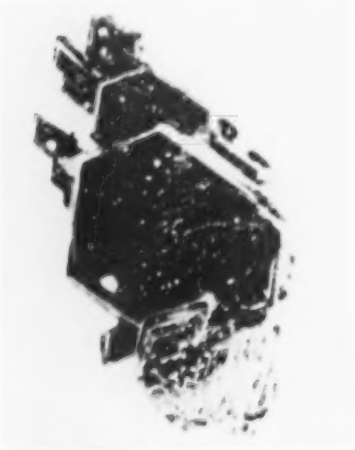

Fig. 12—Electrolytically produced thorium crystal (from NaCl-ThCl$_4$) showing flat surfaces. X19.

Fig. 13—Massive crystal of thorium from electrolysis of NaCl-ThCl$_4$. X18.

Table III. Analysis of Source Electrolytes

Run No.	Total Th, Pct	Cl, Pct	NH_4, Pct	Insolubility, Pct	Na as NaCl, Pct	Total Pct Reported
4	25.9	52.5	0	*	23.8	102.2
8	18.4	55.2	0	*	28.0	101.6
12	38.7	46.2	0	0	14.6	99.4
20	27.6	51.3	0	*	22.2	101.1
24	25.7	52.0	6	0	23.5	101.2

* Slight turbidity.

Table IV. Electrolysis of ThCl$_4$ in Intermediate Scale Cell*

Run No.	Th, Pct	Amp. Hr	Current Amp	Cathodic Current Efficiency, Pct	Hardness Rb	Hardness Vhn
184-71	8.1	685	200 to 230	35	33	82
184-73	16	1270	230	68.1	46	96
223-2	3.3	380	230	40	54	108
223-4	10	1160	220 to 240	65.5	36	85
223-14	13.0	1730	300	61	54	108
223-22	23	3035	360 to 400	56	36	85
223-52	18	1655	350 to 400	64	16	68

* NaCl-ThCl$_4$ melt; 780° to 830°C.

Table V. Spectrographic Analysis of Thorium Produced from Laboratory Scale Electrolytic Runs

Impurity in Ppm	97-174 Powder	97-174 Pellet	97-170* Powder	97-170* Rolled Strip
Ag	2†	1†	2†	1†
Al	20†	30†	30†	30†
B	1†	5†	10†	5†
Be	5†	3†	5†	10†
Ca	100	100	100	100
Cd	0.1†	0.1†	0.1†	0.1
Co	‡	‡	‡	‡
Cu	20†	100†	80†	80†
Fe	110	210	550	350
Ge	‡	‡	‡	‡
Mg	10†	10†	10†	10†
Mn	3†	2†	5†	3†
Mo	‡	‡	‡	‡
Na	300†	150†	150†	150†
Ni*	25	19	300†	200†
P	‡	‡	‡	‡
Pb	5	2	15	5
Sb	‡	‡	‡	‡
Si	100†	50†	50†	30†
Sn	5	6	10	10
U	‡	‡	‡	‡
Zn	‡	‡	‡	‡
As	5	5	5	5
C	27	32		37
HCl, insoluble	3.1 pct		0.2 pct	
Hardness, Rb	31	31	10	

* A nickel stirrer was used in preparation of thorium chloride for Run 97-170.
† Approximate.
‡ Not detected.

The thorium pellets, micrographs of which are shown in Figs. 5 to 8, were analyzed for carbon content and for total HCl insolubles, which would include SiO_2 as well as ThO_2. From the results of these analyses, a relationship was found between the amount of gray phase present in the microstructure and the percentage of material insoluble in concentrated HCl. On this basis, it is probable that the variation in hardness of these specimens was caused mainly by oxygen, although small differences in carbon content probably had some effect. These gray phases have been tentatively identified as being an Fe-Th alloy; subsequent work in which iron contamination was virtually eliminated produced metal without this impurity. The light-colored phase is ThO_2.

The micrographs in Figs. 9 and 10 show the microstructures of arc-melted thorium after 90 pct reduction by cold-rolling and after cold-rolling plus annealing at 1000°C for ½ hr, respectively. The initial hardness of the arc-melted pellet was Rb 15.

Cold-Rolling—Hardness values were obtained as a function of cold reduction for a thorium pellet having an initial hardness of Rb 30. Values of hardness and percentage of reduction in thickness are tabulated in Table VII.

Compactability—Compactability studies were conducted on electrolytic thorium powder by cold pressing in a 1-in. diam die. The results obtained are shown in Fig. 11, which is a plot of green density vs compacting pressure. At compacting pressures of 25 tsi the density was 9.61 per cu cm or 83.5 pct

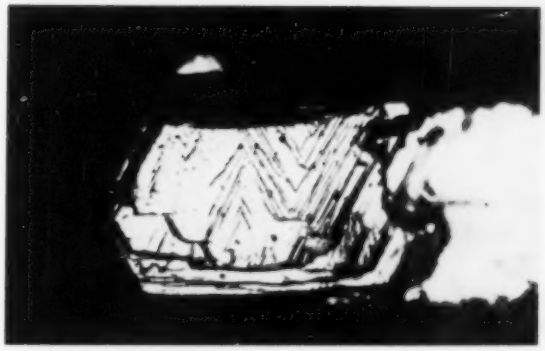

Fig. 14—Layer structure of electrolytically produced thorium crystal. A Laue X-ray photogram was taken with the X-ray beam perpendicular to this face for orientation determination. X250. Reduced approximately 25 pct for reproduction.

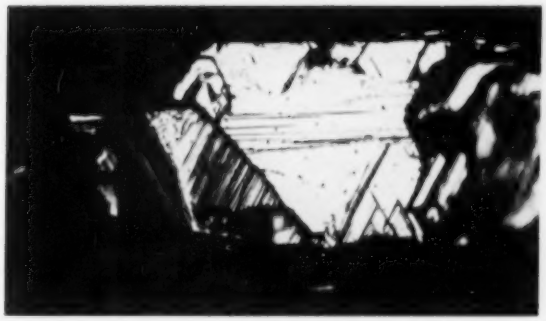

Fig. 15—Adjacent face of the crystal shown in Fig. 14. Notice that a ridge-like rather than a flat surface is observed, indicating faster growth in this direction. X250. Reduced approximately 25 pct for reproduction.

of theoretical density (at 75 tsi a density of 98.0 pct of theoretical can be obtained).

Observations on Thorium Crystals Grown from Fused Salt Electrolytic Baths

For the purpose of observing electrolytic crystal growth characteristics of thorium metal from a fused-salt melt, large, well developed crystals were selected after careful leaching in water. In general, it was observed that both flake crystals with well developed flat surfaces and massive clusters were obtained, see Figs. 12 and 13.

An attempt was made to determine crystallographically the planes responsible for the flat and well developed faces by X-ray techniques. A Laue back-reflection pattern was taken on the crystal shown in Figs. 14 and 15 with the surface depicted in Fig. 15 perpendicular to the X-ray beam. A stereographic plot of the resulting orientation showed that this plane corresponds to (221), which is about 16° from the (111) plane. Since thorium is face-centered-cubic in crystal structure, ordinarily (111), which is the most densely populated plane, would be expected to have the slowest growth rate, and therefore would be predominant. This behavior, however, is modified by the growth conditions and impurities present during crystal growth. In view of this, it is not remarkable that thorium crystals obtained from fused-salt electrolysis have well developed (221) faces.

Conclusions

A process for the production of thorium metal by fused-salt electrolysis has been developed. This process includes the preparation of anhydrous, oxide-free thorium chloride, the electrolysis of this salt in molten sodium chloride, and the recovery of thorium powder of high purity. The use of an all-chloride melt results in an overall process which can be operated on a continuous basis.

The thorium is produced as a granular coarsely crystalline metal. The metal can be consolidated by standard arc-melting techniques. Thorium with an as-cast hardness of RB 5 (Vhn 68) has been produced. It can be cold rolled, drawn, swaged, or otherwise mechanically worked with ease. It is ideally suited for powder metallurgy fabrication techniques.

Primary factors contributing to the success of this process are: 1) high purity source electrolyte, particularly with respect to oxides, insoluble matter, and moisture, 2) the use of an inert atmosphere electrolytic cell during the electrolytic step, and the cooling of the deposit in an inert atmosphere, 3) proper control of bath and cathode operating temperatures, and 4) the use of electrolytic cells of such construction as not to contribute impurities to the electrolytic bath.

Table VI. Comparison Among Hardness, Chemical Composition, and Microstructure of Electrolytic Thorium

Hardness, RB	Analysis, Pct HCl Insoluble	Analysis, Pct C	Amount of Gray Phase in Microstructure
1	1.2	—	Small particles in small amount.
36	1.3	0.02	Small amount.
46	1.67	0.027	Medium amount white phase in gray particles.
59	4.95	0.086	Large amount. Gray particles large in center. Some white phase in gray particles.
70	11.1	0.045	Very large amount. White phase in gray particles.

Summary

A fused salt electrolytic process for the production of pure thorium metal has been developed. This process is based upon an all-chloride electrolytic system in which thorium chloride, dissolved in molten sodium chloride, is electrolyzed to produce a deposit of granular thorium metal powder upon a cathode and chlorine gas at the anode. The process is inherently continuous upon replenishment of the salt bath with additional charges of thorium chloride.

Thorium chloride was prepared in the anhydrous condition using wet chemical procedures by treating an HCl solution of thorium chloride or thorium oxycarbonate with ammonium chloride. The resulting complex ammonium thorium chloride is converted to an oxide-free anhydrous thorium chloride source electrolyte by evaporation, drying, and sublimation in the presence of sodium chloride.

Table VII. Hardness Change with Cold Reduction

Reduction, Pct	Hardness, RB
0	30
15	55
20	55
30	56
40	57
50	67
60	64
70	68
80	69
84.5	71

High purity thorium metal powder was repetitively produced in a laboratory cell and in an expanded scale electrolytic cell by electrolysis of this cell feed. The thorium metal produced was readily compacted, arc-melted, and rolled. Thorium metal ingots with as-cast hardnesses of R_B 5 (Vhn 68) were produced.

The preparation of thorium chloride, descriptions of both electrolytic cells, and some properties of the produced electrolytic thorium metal are given. A bibliography of other processes, electrolytic and nonelectrolytic, for the production of thorium metal is included.

Acknowledgments

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References

[1] A. Atanasiu and M. Babor: *Bulletin de chimie pure et appliquée de la société roumaine de chimie*, 1935-1936, vol. 38, pp. 83-90.
[2] J. J. Berzelius: *Pogg. Ann.*, 1829, vol. 16, p. 385.
[3] A. S. Cachiemaille: British Patent No. 238,347, 1924.
[4] A. S. Cachiemaille: British Patent No. 233,470, 1924.
[5] E. Chauvenet: *Comptes rendus*, 1909, vol. 14, pp. 1267 and 1519.
[6] A. Cotelle and M. Haissinsky: *Comptes rendus*, 1938, vol. 206, pp. 1644-1646.
[7] F. H. Driggs and W. C. Lilliendahl: *Industrial and Engineering Chemistry*, 1930, vol. 22, No. 12, p. 1302.
[8] O. Honigschmidt: *Comptes rendus*, 1905, vol. 142, pp. 157 and 289.
[9] W. Hoppertz: *Chemisches Zentralblatt*, 1904, vol. 1, p. 1383.
[10] G. E. Kaplan: Metallurgy of Thorium, Geneva Conference, 1955.
[11] K. Koiziumi et al.: Japan Patent No. 172,315, 1946.
[12] H. Kuzel and E. Wedekind: U. S. Patent No. 1,088,909, 1914.
[13] R. Lautie: *Bulletin* de la société chimique de France, 1947, vol. 14, pp. 974-977.
[14] W. C. Lilliendahl: U. S. Patent No. 2,537,067, 1951.
[15] J. W. Marden: U. S. Patent No. 1,437,984, 1923.
[16] J. W. Marden, E. Conley, and T. P. Thomas: U. S. Patent No. 1,487,174, 1924.
[17] J. W. Marden: U. S. Patent No. 1,648,954, 1927.
[18] J. W. Marden: *Trans.* Electrochemic Soc., 1936, vol. 68, p. 39.
[19] G. A. Meerson: Powder Metallurgy of Thorium. Geneva Conference, 1955.
[20] H. Moissan and A. Etard: *Comptes rendus*, 1896, vol. 122, p. 573.
[21] H. Moissan and A. Etard: *Annales de Physique*, 1897, vol. 12, No. 7, p. 427.
[22] H. Moissan and O. Honigschmidt: *Annales de Chimie et de physique*, 1905, vol. 8, No. 7, p. 182.
[23] R. Piontelli and A. Builotto: *Chimica e industria*, 1939, vol. 21, pp. 478-491.
[24] H. C. Rentschler, W. C. Lilliendahl, and J. E. Grey: U. S. Patent No. 2,446,062, 1948.
[25] H. Schlect and M. Jahrstoffer: U. S. Patent No. 2,242,759, 1941.
[26] M. A. Steinberg, M. E. Sibert, and E. Wainer: *Journal* Electrochemical Soc., 1954, vol. 101, p. 63.
[27] A. E. Van Arkel: *Reine Metalle*, p. 213. J. Springer, Berlin, 1939.
[28] H. Von Wartenburg, J. Bray, and R. Reinicke: *Ztsch. fur Electrochemie*, 1933, vol. 29, p. 214.
[29] Westinghouse Electric International Co.: British Patent No. 623,160, 1949.
[30] C. Winkler: *Berichte*, 1891, vol. 24, p. 873.

Discussion of this paper sent (2 copies) to AIME by Jan. 1, 1958 will appear in AIME *Transactions* Vol. 212, 1958, and in JOURNAL OF METALS, October 1958.

Technical Note

On Complex Formation in the System Na_3AlF_6-Al_2O_3

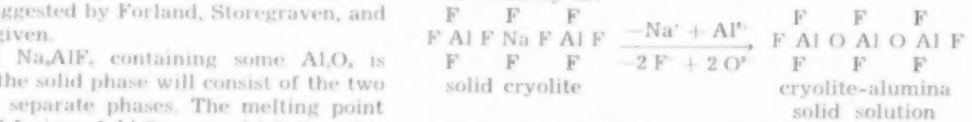
by Tormod Forland

FROM equilibrium measurements on the system NaF-Na_3AlF_6-Al_2O_3-Na_2CO_3-CO_2 with high contents of NaF, Forland, Storegraven, and Urnes[1] concluded that complexes are formed containing two oxygen, three aluminum, and a less defined number of fluorine per complex. The same number of oxygen atoms per complex was also found by cryoscopic measurements for mixtures high in Na_3AlF_6.

In a recent paper by Stokes,[2] some other complex ions, $Al_2OF_6^{--}$ and $AlOF_3^{--}$, have been suggested.

Here an additional argument in favor of the complex $Al_2OF_6^{--}$ suggested by Forland, Storegraven, and Urnes will be given.

When fused Na_3AlF_6 containing some Al_2O_3 is cooled slowly, the solid phase will consist of the two components as separate phases. The melting point and the heat of fusion of Al_2O_3 are so high that this component will form the stable solid phase even though in the liquid state the complex may have a high stability. If, however, the fused mixture is quenched, the decomposition of the oxygen-containing complex and the formation of solid Al_2O_3 does not proceed fast enough, and a solid solution of Al_2O_3 in Na_3AlF_6 is obtained. Zintel and Morawietz[3] obtained cryolite containing 10 pct Al_2O_3 in this way. The density and the lattice parameters of the Al_2O_3 containing cryolite were also measured, and from this it was concluded that the Al_2O_3 enters the cryolite lattice as Al_2AlO_6 groups replacing Na_3AlF_6 groups. However, the experimental data could as well be explained by assuming that one Na^+ ion and two of its neighboring F^- ions are replaced by one Al^{+++} ion and two O^{--} ions. This may be pictured schematically as:



This means that the complex in the solid solution, derived from X-ray and density measurements, is the same as that which Forland, Storegraven, and Urnes derived from equilibrium measurements in the liquid state.

References

[1] T. Forland, H. Storegraven, and S. Urnes: *Ztsch. für anorganische und allgemeine Chemie*, 1955, vol. 279, p. 265.
[2] J. J. Stokes: *AIME Trans.* To be published.
[3] E. Zintel and W. Morawietz: *Ztsch. für anorganische und allgemeine Chemie*, 1939, vol. 240, p. 145.

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Asarco's New Electrolytic Plant at Corpus Christi, Texas

During 1953 the American Smelting and Refining Co. completed construction of an addition to its Corpus Christi operations. This addition was designed to treat fume from Asarco's El Paso and Chihuahua slag fuming plants. The capacity of the plant is from 80 to 90 tons of special high grade zinc for a 24-hr period. Power for the new addition is purchased locally and converted, using mercury arc rectifiers.

by A. C. Jephson and R. E. Allen

ELECTROLYTIC zinc plants of the American Smelting and Refining Co. are located adjacent to the present city limits of Corpus Christi, Texas. The original plant commenced operations during 1942, and is designed for the production of special high grade zinc from zinc sulfide concentrates.[1] Subsequent changes include the erection of an additional acid plant during 1950, and additions for increased generating and production capacity during 1951.

New Electrolytic Plant—The new electrolytic plant is a separate unit erected for the treatment of densified fume produced at Asarco plants located in El Paso, Texas and Chihuahua, Mexico. Construction was completed and operation commenced during June, 1953.

Decision for the erection of a separate plant for the treatment of densified fume is based on several factors. One of the principal reasons is the assurance of continued production rate of the original plant, which might have been jeopardized by combined treatment of calcine and fume. Of equal importance is the advantage of locating a plant on a site with adequate space for eventual expansion.

General Description—The new plant for the treatment of densified fume consists of four main buildings for the following operations: storage and grinding of fume, leaching and purification, electrolyzing and casting, and rectifier units. Auxiliary buildings include a baghouse, reagent storage, and a lunch room.

A. C. JEPHSON and R. E. ALLEN, Members AIME, are Manager and Superintendent, respectively, Electrolytic Plant, American Smelting and Refining Co., Corpus Christi, Texas.

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Leaching of ground fume with electrolyte from the cells is a batch type operation in tanks equipped with mechanical agitators and weightometers. Completed leaches are pressure filtered, the resultant residue being recovered for shipment to El Paso by conventional use of thickeners, drum type vacuum filters, and a direct-fired dryer. Filtrates from the filter section are purified in mechanically agitated tanks, filtered after completion through plate and frame presses, and then pumped to an evaporative type cooling tower. Solution discharged from the basin of the cooling tower is collected in storage tanks for use in the cells.

The cool purified solutions are pumped as required from storage to the solution circuit for circulation of electrolyte through the cells. Except for the addition of purified feed solution and withdrawal of electrolyte for leaching, the circulating system for the cells is essentially a closed continuous circuit that includes the use of evaporative cooling towers for control of solution temperatures. Aluminum cathodes and Ag-Pb anodes are used for electrolysis, which is maintained at a current density of about 82 amp per sq ft. Cathode zinc produced is melted in a gas-fired reverberatory furnace and then cast into slabs on a straight line casting machine.

Unloading and Storage—Fume produced by the Chihuahua plant is shipped in box cars, and fume by the El Paso plant in hopper bottom dump cars. Shipments as received are weighed on a 75-ton capacity railroad scale, sampled, and then moved over one of the two unloading hoppers with a car puller. The cars are then unloaded with mechanized equipment, a car scoop being used for unloading of box cars and a car shaker for the hopper bottom cars.

Table I. Monthly Averages for First Six Months 1955

Tons fume leached	3,385
Tons residue produced	220
Tons zinc dust used	175
Tons copper precipitate shipped	20
Tons cathode zinc produced	2,795
Tons slab zinc cast	2,720
Cell load, amp	19,400
Pct current efficiency	88.6

Table II. Average Analysis of Slab Zinc, Pct

Pb	Cd	Cu	Fe	Zn, By Difference
0.0013	0.0005	0.0003	0.0007	99.9972

From the unloading hoppers the fume is conveyed by belt to a bucket elevator which, in turn, discharges to either of two parallel belts located above the four covered concrete storage bins. Each of the parallel belts is equipped with movable trippers for final discharge into either of the four concrete storage bins. Normal capacity of each bin is 2500 tons; rated capacity of the bucket elevator is 230 tons per hr. The remainder of the conveying system has a capacity of 200 tons per hr.

Drying and Grinding—The grinding unit, as previously mentioned, is located in the building used for storage of fume. The unit consists of a gas-fired rotary dryer, an air-swept ball mill, and conveying equipment.

Fume for process is removed from storage with a power shovel, discharged into a hopper, and then transferred by conveyor belts and a bucket elevator to an 85-ton capacity bin. The bin, which is equipped with an adjustable gate, discharges by belt at a controlled rate to the dryer.

The gas-fired rotary dryer is 4 ft in diam by 20 ft in length, with an internal spiral and lifter arrangement to facilitate drying. Combustion gases from the dryer are passed through a forced draft cyclone for recovery of dust. Dry fume from the dryer is transferred to the feed hopper for the ball mill with a bucket elevator.

A 7 ft by 48 in. Hardinge air-swept ball mill, equipped in conventional manner with a classifier and cyclone product collector, is used for grinding the fume. Auxiliary equipment consists of a disk feeder for the mill and a bag filter for recovery of dust contained in the air stream vented from the circuit. The bag filter and collector are discharged into a screw conveyor for transfer of ground fume and dust to storage bins at the leaching department.

The production rate of the mill is about 7½ tons per hr; ball consumption is about 0.07 lb per ton of fume ground. Typical screen analysis of the ground fume is: 1 pct on 100 mesh, 5 pct on 200 mesh, 25 pct on 325 mesh, and about 69 pct as −325 mesh.

Leaching—Ground fume from either of two 500-ton capacity storage bins is transferred with screw conveyors and a bucket elevator to 25-ton bins located at each of the three ventilated leaching tanks. The leaching tanks, which are designed for an operating volume of about 21,000 gallons each, are of wood-stave construction, lined with Sb-Pb sheet and acid-proof brick. Fume is discharged into leaching tanks at a controlled rate by the use of a screw conveyor and weightometer. The agitator assembly, which is constructed of type 316 stainless steel, consists of an 8-in. diam shaft to which a reinforced channel type cross-arm is attached. Angle positioned lifters, attached to the cross-arm, and baffles suspended through the cover of the tank, are included for effective agitation. A 15-hp motor and a spur type reduction gear are used for driving the agitator at a rate of about 10 rpm.

Leaching, as previously indicated, is a batch type of operation and is essentially a two-stage method of treatment. The initial stage consists of pumping about 17,000 gallons of electrolyte and 4,000 gallons of wash solution from the filters into an agitator and determining the acid content of the mixture. Using typical data of previous charges, a calculated amount of fume is then added with a weightometer for reduction of acid concentration from about 155 g per liter to the range of 5 to 6 g per liter. Ground MnO_2 ore is also added during the initial stage for oxidation of soluble iron. After a 2-hr period of agitation the acid content is determined and sufficient fume added at intervals for a final stage of neutralization. The final stage for neutralization usually requires 1 to 2 hr and is determined by titration of samples. Before a charge is released for filtration, the filtering rate of the pulp and ferrous iron content of filtrate are checked. Occasional charges which are not considered satisfactory are reacidified to about 5 g per liter, MnO_2 added if required, and the solution again neutralized.

Filtering and Residue Recovery—The filtering section consists of six Burt filters, two thickeners, two drum type vacuum filters, a residue dryer, and the usual auxiliary equipment. Tanks for intermediate storage of pulp are not included. Completed charges are pumped direct from the leaching tanks into the Burt filters.

The Burt filters, each 5 ft in diam by 40 ft in length, are lined with ¼ in. rubber. The operating floors for the filters and leaching tanks are at the same elevation. Other than lining, the filters are of conventional design with the usual complement of 32 fluted surface filter boards. Strength of the filter boards has been improved by the substitution of stainless steel bolts for Everdur, and additional reinforcement of the center bolt and spigot sections. The use of synthetic cloth instead of the usual type of canvas for covering the boards is in the experimental stage.

Operation of the Burt filters is similar to descriptions previously published.[1] Briefly, the cycle consists of pumping pulp from a leaching tank into a rotating filter and applying air pressure until pressure gages indicate that the initial filtration stage is completed. In a similar manner, three successive additions of wash water are pumped into the filter for a countercurrent type of washing. Resultant filtrates, in each case, are advanced to storage tanks containing solutions of increased gravity. Weak wash water is then added and the cloths pulsated with vacuum for repulping and discharge of the residue.

The residue slurry from the filters is then discharged into the first of two 30-ft thickeners which are operated in series. The underflow from the second thickener is pumped to one of the two drum type vacuum filters for recovery of residue which is dried and stored for shipment to a lead smelter. The rotary dryer, as previously mentioned, is 4 ft in diam by 20 ft in length. Residue from the dryer is stored in bins until it is sufficient for shipment.

Table III. Typical Analysis of Solutions

	G per Liter		Mg per Liter			
	Acid	Zn	Ge	Co	Fe	F
Burt filtrate	—	160	1 to 25	1 to 1.5	10	Not
First purification	—	165	0.1 to 0.2	0.1	10	deter-
Final purification	—	170	<0.006	0.1	10	mined
Electrolyte	190	65	<0.006	0.1	15	4

Table IV. Typical Analysis of Fume and By-Products

	Zn	Pb	Fe	Ge	F
Fume leached	76 to 77.5	0.5 to 1.7	0.7 to 1.5	0.004 to 0.06	0.003 to 0.01
Residue produced	8.5 to 12.5	7.0 to 21.0	11 to 17	0.03 to 0.4	0.008 to 0.24
			Cu		
Copper precipitate shipped	1.0	3.5 to 5	40 to 50	0.3 to 0.75	

Purification—Two variations are incorporated in the design and construction of the purification section. Each of the four purifiers has an operating volume of 40,000 gallons as compared with the 20,000 gallon capacity of those used at the original plant. Another departure is the use of aluminum alloy plates and frames in the filter presses instead of the usual bronze type.

The purifiers, each 30 ft in diam by 10½ ft deep, are unlined wood-stave tanks with steam coils for heating the solutions. Two 30-in. diam stacks, each equipped with 1900 cfm forced draft fans, are used on each tank to assure adequate ventilation. The agitator assembly, which is constructed of copper alloy, consists of an 8-in. diam shaft to which an 8-in. diam cross-arm is attached. A 20 hp motor and reduction gear are used for driving the agitator at a rate of about 6.5 rpm.

Purification is based on a two-stage method of treatment. The first stage is primarily for reduction of germanium content to about 0.2 mg per liter. Completed charges are filtered and discharged direct from the filter press into a second-stage tank for final purification. All of the presses are the closed delivery type and are 36 in. in size. Filter cloth and Kraft paper are used in the usual manner to assure clarity of solution.

Typical operation for the first-stage treatment consists of pumping about 40,000 gallons of Burt filtrate into a purifier, heating the solution to about 90°C, and adjusting the acid content to about 2 g per liter. Part of the press cake from previous charges and all of the press cake from the second-stage treatment are added during the initial period of operation. Remainder of treatment, which usually requires about 4 hr, consists of adding zinc dust at a gradual rate with a belt type feeder. Although a rapid test has not been developed for germanium, the operators have reasonable assurance of satisfactory removal by maintaining a pH of about 4 to 5, and varying conditions as indicated by previous charges. Press cake not required for treatment of subsequent charges is shipped to a copper smelter. Completed charges are filtered and discharged direct from the press into one of the two tanks used for second-stage purification.

The second-stage treatment for final purification usually requires 4 hr for completion. The charges are started by adjusting the solution to 4 pH, and adding 300 lb copper sulfate and about 0.1 lb arsenious oxide. During the treatment stage zinc dust is added at a uniform rate with a feeder and additional copper sulfate as required. Electrolyte is added to maintain a pH of 4 to 5 and temperature of solution permitted to decrease from about 80° to 70°C. As previously indicated, the germanium content of the solution is not determined by the operators. However, satisfactory tests for cobalt and arsenic usually give assurance that the solution is of sufficient purity for electrolysis. Solutions of such purity are then filtered and discharged from the presses into storage tanks.

Cell Department—Power is purchased from a local utility company and converted to dc current for operation of the cells. The initial voltage of 69,000 is reduced to 12,000 with two 7,500 kva transformers. Three 12-phase mercury arc rectifiers are then used for conversion to dc current, which is transmitted to the cells by a common bus bar arrangement. Although the normal rating of each of the three rectifiers is 5,600 amp at 570 volts, the cells are presently operated at 19,500 amp and 610 volts. Power from the plant ac generating system is available for emergency by use of an interlocking system.

Operation of a 600 dc volt circuit in the humid climate of Corpus Christi requires design for control of stray currents. Design for control of stray currents includes the use of brick-lined cells and of launders constructed of plastic for flow of electrolyte to and from the cells. In addition, the feed launders are located about 6 ft above each bank of cells and the return launders, which are sloped, from 3 to 4 ft below the outlets of the cells. Removable porcelain pipes are used for directing electrolyte from the feed launders to the cells.

The 196 cells used for electrolysis are arranged 14 cells to a bank in 14 parallel rows. The cells are constructed of concrete and are lined with asphalt and plastic base materials, which in turn are protected by an inner lining of 1¼ in. acid-proof brick. The top course of the brick lining is secured by a lead cap which extends over the top and outer edge of the cell. Each cell is designed for an operating volume of 750 gallons of solution and is equipped with 29 Ag-Pb anodes and 28 aluminum cathodes. The anodes and cathodes are identical to those used in the original plant and are supported in the same manner on notched porcelain insulators located on the edge of the cell.

The general arrangement of the bus bars in each plant is similar in that they are located adjacent to the end cells of each bank and have a shunt arrangement for release of companion rows for cleaning. Essential difference in design is the use of a light insert bar instead of a heavy swing-type shunt bar. Installation of the stripping floor at the same elevation as the top of the cells is another change which is a decided convenience for operations.

A closed system of circulation is used for continuous flow of electrolyte through the individual cells. Return launders for each of the cell banks are positioned for flow of electrolyte into a main collecting launder and discharge into either of two 55,000 gallon capacity lead-lined tanks. Pumps are then used for transfer to three evaporative type cooling towers which are packed with a staggered arrangement of wooden slats for dispersion of solu-

tion. Each unit is provided with a 158,000 cfm fan positioned for right angle flow of air through the tower.

Solution from the basins of the towers overflows into a common launder and discharges into either of two 155,000 gallon capacity lead-lined storage tanks. The solution is then pumped to a main feed launder which has controlled outlets for distribution to each of the bank feed launders. The feed launders also have controlled outlets for regulation of flow to individual cells. The rate of flow is usually about 15 gpm per cell.

As previously mentioned, electrolyte is pumped from the circulating system to the leaching tanks and feed solution added from the purification department. Separate pumps are used for transfer of solution from the 55,000 gallon tanks to the leaching department. Feed solution from the purification section is pumped at a controlled rate into the discharge launder of the cooling towers. Reagent feeders for the addition of cresylic acid, sodium silicate, and gum arabic are located for discharge into the 155,000 gallon storage tanks. A slurry of strontium carbonate is also added at the point for control of the lead content of the cathode zinc.

The 14 banks of cells are rotated for operation; 12 are used for electrolysis and two are shunted out for cleaning of anodes which is usually maintained on a 16-day cycle. Anodes removed for cleaning are hung in a vertical position on a circular type conveyor chain. The chain conveys the anodes in sequence through a dryer, a rapper, two sets of brushes, and a washer. The anodes are removed, placed in a rack, and returned to the cells for replacement and alignment.

Cells used for electrolysis are stripped after a 16-hr period of deposition. The alternate cathodes in a cell are removed at one time, placed in a rack, washed, and then stripped with a chisel and hammer. The cathode sticks are checked and contacts washed before replacement in the cells.

The zinc cathodes are transferred with a gasoline driven lift truck to a scale for weighing, and then to the charge floor for gradual additions into the melting furnace.

Casting—The gas-fired reverbatory furnace used for melting zinc cathodes is located at the ground level beneath the edge of the charge floor. Cathodes are charged into the furnace through a chute attached to an opening in the flat suspended arch. The chute has two swing-dampers positioned about 3 ft apart for preventing escape of furnace gases.

The inside area of the furnace is 12 ft by 21 ft and the average depth of the bath is about 2.3 ft, which is equivalent to 140 tons capacity. Two dipping wells located on the flue end of the furnace are separated from the combustion zone with a bridge wall. Three low pressure gas burners on the opposite end of the furnace have controls for adjustment of flame patterns, and auxiliaries for maintaining desired ratio of the air-gas mixture.

Combustion gases from the furnace are drawn through a pipe cooler with a 19,000 cfm fan and discharged into a baghouse for recovery of dust. The baghouse consists of two sections, each containing 42 bags which are 18 in. in diam by 25 ft in length. The cellars are usually cleaned once a month by sluicing the dust into a sump and then pumping the slurry into an agitator. After a series of washes and decantations for removal of water soluble chlorides, the final slurry is pumped into the solution circuit of the cell department.

After completion of casting, each crew rabbles ammonium chloride into the skim layer and adjusts the burners for the next shift. Skim is removed at 16-hr intervals and, after cooling, is transferred to a hammer-mill for separation and recovery of metallics. The metallics are returned to the furnace and the oxide portion to an agitator for removal of water soluble chlorides. After settling and decantation, the skim is dissolved in electrolyte and pumped to the leaching department.

The straight line type of machine presently used by the original plant is to be installed for casting. The machine has 140 molds mounted on an endless chain which is positioned on a slope for elevation and discharge of the slabs to a bench. The essential feature of the machine is the design of the structure and drive for elimination of vibration. Drive assembly for the machine consists of a 10 hp motor connected to dynamatic variable speed coupling, which in turn is connected to a worm reduction gear. Variation of mold speed is controlled by the ladle operator. Slabs discharged from the machine are stacked for transfer to the scales for weighing. After weighing and check-weighing the stacks are stored on the dock for shipment.

Operating Data—Typical analyses and production data are shown in Tables I to IV.

Reference

[1] *AIME Trans.*, 1944, vol. 159, p. 194.

Discussion of this paper sent (2 copies) to AIME by Aug. 1, 1957 will appear in AIME *Transactions* Vol. 212, 1958, and in JOURNAL OF METALS, October 1958.

Technical Note

Mass Spectrometric Examination of Anode Gases from Aluminum Reduction Cells

by Jack L. Henry and R. D. Holliday

GASEOUS products of an aluminum reduction cell consist mainly of carbon dioxide and carbon monoxide. Sulfur dioxide, hydrogen fluoride, and hydrogen sulfide have also been conclusively identified. Carbon tetrafluoride has been observed only during the period when the anode is polarized.[1] This period, known as *anode effect*, occurs when the alumina content of the molten bath approaches depletion.[2] Increased resistance at the polarized anode results in a voltage rise from a normal 5 volts to as

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high as 60 volts in order to sustain the current. Although the anode effect is terminated as quickly as possible, the gas evolution rate and electrolyte temperature increase during its course.

Many other gaseous products have also been suggested, as would be expected from the complexity of the system. In view of the many uncertainties in composition and difficulties in chemical analysis, a complete qualitative and quantitative analysis of anode gas was made with the mass spectrometer.[3,4]

Experimental

Thirteen anode gas samples were taken from commercial reduction cells of both the prebaked anode and the continuous or Söderberg anode types. Nearly completely burned gas as well as samples showing a small degree of combustion were taken during normal operation and anode effect. Gas was drawn into evacuated glass sample bulbs through a Vycor tube which was packed with pelletized sodium fluoride to remove the hydrogen fluoride.[5] Slightly burned gas samples were obtained from within a steel can mounted over a hole in the bath crust, while the more completely burned samples were taken from above open holes. All samples were analyzed by the Consolidated Electrodynamics Corp. in Pasadena, Calif.

Results and Discussion

The compositions of gas samples from the Söderberg anode cell are shown in Table I. Corresponding compositions of gas taken from the prebaked anode cells are given in Table II. It is evident that the composition is substantially the same for both types of reduction cells. Aside from carbon dioxide and carbon monoxide, carbon tetrafluoride is the only gas appearing in quantity, and it is evolved only during anode effect. The nonappearance of carbon tetrafluoride during normal operation does not rule out the possibility that CF_4 is an initial product, but that pyrolysis to CO and HF occurs as the gas escapes. Conditions in the cell closely resemble those employed for the estimation of fluorocarbons by pyrolytic hydrolysis to form HF.[6] The only higher fluorocarbon detected was hexafluoroethane. Its low concentration indicates that the only serious fluoride loss in the form of inert fluorocarbons may be attributed to CF_4.

It is of interest to note that several sulfur gases are evolved from a reduction cell. The primary sulfur compound appears to be carbonyl sulfide, although substantial amounts of carbon disulfide are generated during anode effect. COS is formed when carbon, oxygen, and sulfur or their compounds CO, CS_2, and SO_2 are brought together at high temperature.[7]

$$COS \rightleftharpoons CO + S$$
$$2COS \rightleftharpoons CO_2 + CS_2$$

Since the CO_2 concentration is high near the anode surface, mass action would favor the formation of COS. During anode effect, however, when the CO_2 concentration is lower, more CS_2 should be formed. Higher local temperature during anode effect would also promote the formation of the more endothermic CS_2. Since each atom of sulfur occupies two carbon bonds and prohibits the carbon from carrying its full share of oxygen as CO_2 during normal depolarization, this constitutes a mechanism of carbon consumption.

Sulfur dioxide is formed by the oxidation of the COS and CS_2 while hydrogen sulfide is presumably formed by hydrolysis. Elemental sulfur has been found in particulate matter collected in the absence of air. It is possible that the reduced forms of sulfur may result from reduction at the cathode. Cyclic oxidation and reduction of sulfur compounds at the anode and cathode may be a factor in cell current efficiency.[8]

Free hydrogen undoubtedly results from cracking of anodic hydrocarbons. The argon:nitrogen ratio is nearly that for air, indicating that nitrogen is probably not a cell product.

Hydrogen fluoride was purposely removed from mass spectrometer samples, and has been measured by other means. Pure unburned gas from small scale experimental cells has been found to contain approximately 0.5 volume pct HF, assuming a formula weight of 20. Anode hydrocarbons appear to provide the hydrogen for the formation of HF. Additional HF is formed when volatilized or entrained fluorides contact the moisture in the air. The present data indicate that at least an additional 0.5 volume pct, based on the original gas volume, results from the thermal hydrolysis of such material.

Table I. Composition of Anode Gas from a Söderberg Cell; HF and SiF_4 Removed

	Volume Pct			
	During Normal Operation		During Anode Effect	
Gaseous Component	Very Slightly Burned	Nearly Completely Burned	Very Slightly Burned	Nearly Completely Burned
CO_2	44.19	39.77	16.28	7.52
CO	42.07	12.98	64.25	1.80
N_2	10.64	46.50	2.33	74.09
O_2	2.60	8.98	0.48	14.33
A	0.12	0.54	—	0.85
H_2O	0.04	0.10	—	—
H_2	0.16	—	0.28	—
SO_2	—	0.05	0.01	0.12
H_2S	—	0.05	—	0.06
COS	0.18	0.03	0.50	—
CS_2	—	—	1.01	—
CF_4	—	—	14.72	1.22
C_2F_6	—	—	0.12	—

Table II. Composition of Anode Gas from Prebaked Anode Cells; HF and SiF_4 Removed

	Volume Pct			
	During Normal Operation		During Anode Effect	
Gaseous Component	Very Slightly Burned	Nearly Completely Burned	Very Slightly Burned	Nearly Completely Burned
CO_2	43.48	32.45	11.25	21.70
CO	18.54	10.75	68.92	19.43
N_2	29.08	47.24	2.71	54.77
O_2	6.22	8.95	0.13	2.12
A	0.32	0.52	—	0.58
H_2O	1.78	—	—	—
H_2	—	—	3.71	0.21
SO_2	—	0.07	0.01	—
H_2S	0.04	—	—	—
COS	0.31	0.02	0.35	0.03
CS_2	—	—	0.39	—
CF_4	—	—	12.53	1.16
C_2F_6	—	—	—	—

References

[1] N. Kameyama et al.: Carbon Fluorides in the Anode Gas of the Alumina Reduction Furnace. Twelfth International Congress of Pure and Applied Chemistry. New York, 1951.

[2] J. D. Edwards, F. C. Frary, and Z. Jeffries: Aluminum and Its Production, Vol. 1. *The Aluminum Industry*. McGraw-Hill Book Co. New York, 1930.

[3] S. M. Rock: *Analytical Chemistry*, 1951, vol. 23, pp. 261-268.

[4] H. W. Washburn, H. F. Wiley, and S. M. Rock: *Industrial & Engineering Chemistry*, Anal. Ed. 1943, vol. 15, No. 9, pp. 541-547.

[5] F. A. Lenfesty, T. D. Farr, and J. C. Brosheer: *Industrial & Engineering Chemistry*, 1952, vol. 44, pp. 1448-1450.

[6] J. H. Simons: *Fluorine Chemistry*, vol. 2, p. 358. Academic Press Inc. New York, 1954.

[7] F. Ephriam: *Inorganic Chemistry*, 4th Ed., pp. 846-847. Norderman Publishing Co. Inc. New York, 1943.

[8] T. G. Pearson: The Chemical Background of the Aluminum Industry, p. 43. Royal Institute of Chemistry, Lectures, Monographs and Reports, London, 1955.

Dissolution of Pyrite Ores in Acid Chlorine Solutions

An apparatus and technique is described for reacting a known area of sulfide ore with a known volume of chlorine water and measuring the rate of dissolution of the ore. Pyrite, under all conditions studied, produces only ferric ions and sulfate ions, and the reaction is diffusion controlled with an energy of activation of about 5000 cal per mole.

by M. I. Sherman and J. D. H. Strickland

USE of a hydrometallurgical approach to the oxidation of sulfide ores and extraction of metals therefrom may have advantages over the more common smelting techniques when a low grade deposit is difficult to concentrate or the subsequent separation of metals, coexisting in the ore, is laborious by any known smelting operation. For economic reasons, the most promising oxidants are either atmospheric oxygen or electric power.

The use of oxygen, or air under pressure, has recently been revised. Pyrrhotite has been converted to iron oxide and elementary sulfur[1] and a variety of sulfides have been treated by Forward and coworkers.[2,3] Generally sulfate is the end form of the sulfur but with galena in an acid medium, elementary sulfur can be formed.[3] For economic reasons chlorine and ferric iron salts are about the only possible alternatives to the atmosphere as oxidizing agents for base metal sulfides. If aqueous solutions of chlorine or ferric iron are employed, the reduction products can be oxidized electrolytically *in situ* and used again, thus acting as *catalysts* for electric power as oxidant. The use of ferric salts for this purpose is established hydrometallurgical practice[5] but, although chlorine gas has been employed in the dry state at an elevated temperature, its use in aqueous solution at or near room temperature has not found favor.

The reaction of chlorine water with the soluble sulfide ion has been studied by several workers,[6,7] and both sulfate and elemental sulfur are found as end products, the latter being favored by the presence of a low concentration of oxidant relative to that of sulfide in solutions of about pH 9 to 10. Of direct bearing on the work in hand are an early American patent[8] and a recent Austrian patent.[9] The former advocates stirring powdered ore with an aqueous solution of ferric chloride chlorine oxides and chlorine. In the latter it is claimed that both metal and sulfur can be obtained by electrolysis, in a diaphragm cell, of a metal ore slurry in brine. Details in these patents are scant and no data or explanation is given for the mechanism of the reaction which, in the Austrian work, is attributed to the (unlikely) action of *nascent* chlorine at the anode surface. No mention is made of possible differences in behaviour between various ores.

M. I. SHERMAN is associated with British Columbia Research Council, University of British Columbia, Vancouver, Canada. J. D. H. STRICKLAND is with Fisheries Research Board of Canada, Pacific Oceanographic Group, Nanaimo, Canada.

TP 4428D. Manuscript, Feb. 15, 1956. New York Meeting, February 1956.

Apparatus

A complication encountered when working with chlorine water is that a serious loss of chlorine occurs by gas partitioning unless an enclosed system is used and any air space in the apparatus is kept very small and constant. Arrangements were made, therefore, to take out samples for analysis without letting air into the system to replace the liquid removed. For convenience in studying a heterogeneous reaction the apparatus was so designed that a reproducible controlled stirring rate could be maintained and the ratio of surface area of ore to volume of solution was approximately constant throughout any experiment.

The apparatus used is shown in Fig. 1. The ground ore was placed in the horizontal cylindrical vessel, *A*, of about 1 liter capacity, heated by a constant temperature circulating bath pumping water through the concentric jacket, *B*. By adding chromate to this water, an ultraviolet radiation filter effectively surrounded the reaction vessel, greatly reducing any possible photochemical decomposition of chlorine solutions. Stirring was effected by glass paddles, *C*, attached by an axle to a magnet which was rotated by another powerful Alnico magnet, *D*, outside the glass end, this magnet being itself rotated by an electric motor electronically controlled to constant speed. Speed could be varied from about 150 to 900 rpm and was measured and held to within 1 pct of a given value. The end of the reaction vessel remote from the stirring magnet was closed by another one-ended glass cylinder, *E*, connected by thin polyethylene bellows, *F*, clamped by screw clamps and watertight rubber gaskets to the main vessel. Through *E*, a glass electrode and calomel electrode projected into the solution and a hypodermic syringe pierced a small bung and allowed acid or alkaline to be added to maintain a constant pH. By pushing the fully extended bellows until the two cylinders touched, from 50 to 100 ml of solution could be forced out through a sintered disk into the three-way tap system, *G*, either to waste (for flushing purposes) or up into a 10 ml burette where the solution could subsequently be measured out for analysis. The ore samples were introduced at *H*, the tube being stoppered by a thermometer of −1 to +52°C range, graduated to 0.1°C intervals. To prevent ore from being ground in the end bearings of the stirrer these bearings were pro-

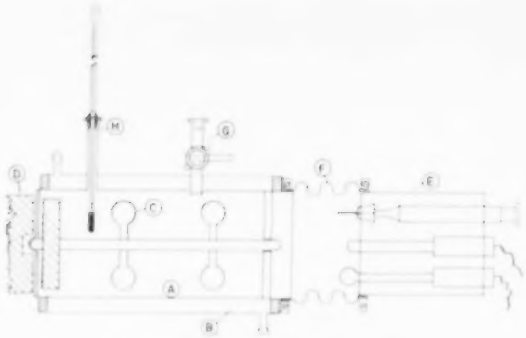

Fig. 1—Schematic diagram of apparatus.

Table I. Experimental Data

Experiments Illustrate	Conditions	Temperature, °C	k_1 Cm per Min for Chlorine	k_1 Cm per Min for Chlorine Dioxide
Effect of Temperature	0.1M H^+ pH 1.0 300 rpm	10.0	0.221	0.119
		25.0	0.328	0.179
		40.0	0.503	0.280
Effect of Acidity	0.5M H^+ pH 0.40 300 rpm	25.0	0.326	
	0.02M H^+ pH 2.05 300 rpm	25.0	0.328	
Effect of Stirring	0.1M H^+ pH 1.0 675 rpm	25.2	0.862	0.457

tected by polyethylene disks attached to the rotating shaft (not shown). To prevent ore collecting and stagnating in the folds of the bellows, these were lined by a stiff cylinder of thicker polyethylene (also not shown), which was fastened to the end cylinder and slid in and out of the main reactor vessel. The whole equipment was securely fastened in a wooden cradle and the apparatus could be tilted and held, if desired, at an angle to the horizontal to assist in maintaining an even layer of ore on the bottom of the cylinder.

Experimental Procedure

A large sample of pyrite from British Columbia, assaying at better than 97 pct FeS_2, was crushed and wet-sieved to give a fraction −10 + 14 Tyler screen. The particles were irregularly shaped, somewhere between cubes and spheres, and an estimate of the apparent surface per gram was obtained by weighing a known number of particles and comparing the volume with that calculated, assuming each particle a cube of side equal to the mean mesh opening. The volume *shape factor* thus obtained was used as an area shape factor and, although the justification for such a procedure can be questioned, it was considered that using this factor led to less error than neglecting it.

The apparatus was assembled and filled with a solution of oxidant, in a medium of desired ionic composition and pH, so that no air remained in the vessel. The solution was stirred and the jacketing water circulated until the correct temperature was reached. A known weight of ore was quickly added through the thermometer outlet and a stop watch started. At known time intervals the bellows were compressed and liquid removed. One ml was sent to waste in order to flush out the equipment, then the three-way tap was turned so that 8 ml could be sent up into a burette

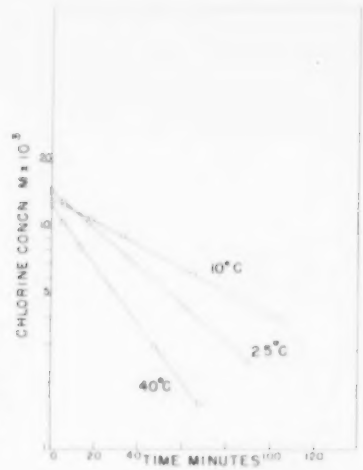

Fig. 2—Plot of chlorine concentration against time for 56 sq cm of pyrite surface, solution stirred at 300 rpm at various temperatures.

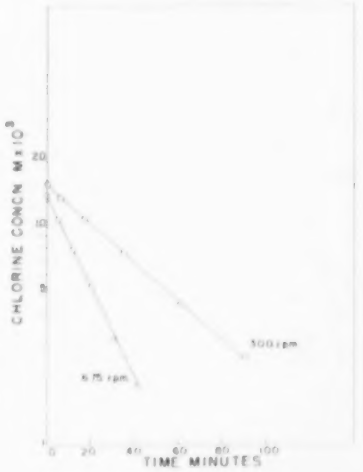

Fig. 3—Plot of chlorine concentration against time for 56 sq cm of pyrite surface at 25°C; variable stirring.

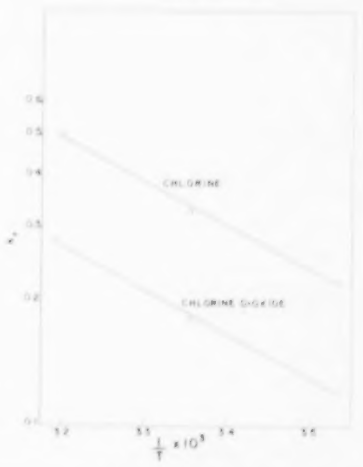

Fig. 4—Arrhenius plot for oxidation of pyrite by chlorine and chlorine dioxide solutions.

from which a 5 ml aliquot was taken for oxidant determination, 1 ml for sulfate determination, and 1 ml for the determination of iron. At the end of an experiment, during which from five to eight points were taken, the remaining ore was removed, washed well with water, and air dried.

To prevent complications due to hydrolysis of ferric ions or of chlorine, the pH was kept below about 2. To maintain a sensibly constant ionic strength during a run, all work was carried out in the pre-

sence of an excess inert electrolyte. Although sodium perchlorate is generally ideal for this purpose, sodium chloride was used in this work as it better simulated any likely practical conditions and, in the case of lead ores,[12] prevented the precipitation of lead sulfate. Sodium chloride and hydrochloric acid were obtained from analytical grade sources and chlorine was taken from a cylinder.

The method used for determining chlorine was by a spectrophotometric technique developed especially for this investigation.[13] Iron was determined absorptiometrically with o-phenanthroline; and sulfate, after distillation as hydrogen sulfide by Luke's[14] procedure, was determined absorptiometrically as Lauth's violet.[15]

Results and Discussion

In a large number of representative points the results for chlorine consumed and ferric and sulfate ions brought into solution showed that, within the limits of experimental error, only sulfate was formed from the disulfide ions in the ore. The kinetics of the reaction are adequately expressed, therefore, by curves showing the consumption of chlorine with time. Examples of these are given, as plots of log chlorine concentration against time in minutes, by Figs. 2 and 3, showing the effect of temperature (10° to 40°C) and rate of stirring (300 and 675 rpm). Visually the surface of pyrite particles after treatment was unchanged except for microscopic etching.

For a first order heterogeneous reaction with chlorine water a reaction constant k can be defined by

$$\frac{-dC'_a}{dt} = k \cdot \frac{A}{V} \cdot C'_a \qquad [1]$$

where $-dC'_a/dt$ is the rate of decrease of oxidant concentration when, at a concentration of C'_a mole per liter, A is the area of the ore in sq cm, and V the volume of the solution in cu cm. If t is in minutes, k has the units of cm·min^{-1}. If the chemical reaction is very rapid the observed rate of reaction will depend solely on the rate with which oxidant molecules can diffuse through a layer of solution close to the ore, over which a concentration gradient is found, there being zero concentration at the surface and a concentration C'_a outside the layer. In this case k should equal a diffusion or transport constant k_t defined by

$$k_t = \frac{60D}{L} \qquad [2]$$

where D is the Fick diffusion constant in cm^2 sec^{-1} and L the length, in cm, of a hypothetical diffusion layer where a linear concentration gradient from C'_a to zero applies. Although the existence of such a simple layer is in dispute the concept leads to a satisfactory qualitative description of many heterogeneous transport-controlled reactions.[16] The k_t should be particularly sensitive to the rate of stirring and, provided that the stirring rate, r, is appreciable, a relationship

$$k_t \propto r^b \qquad [3]$$

should apply with b having a value above 0.5. The energy of activation E_t should be low, only a few thousand calories, and factors affecting the chemical reaction at the surface, such as pH, should have no effect.

The data given in Table I show that transport control applied to all the experiments. In every case 5.05 g of pyrite, giving an estimated surface area of 56 sq cm, reacted with an initial volume of between 910 and 924 cu cm of a solution, 0.5M with respect to chloride, the cations being sodium or hydrogen ions. The values for k_t calculated, using the integrated form of Eq. 1, are given in Table I for various experimental conditions.

The pH is seen to have no effect on the reaction for which b, Eq. 3, has a value of 1.2. The mean energy of activation between 10° and 40°C, as determined from the Arrhenious plot, Fig. 4, is 4900 cal per mole. This mean value is reasonable for a diffusion-controlled reaction in aqueous solutions, and the slope is somewhat less at lower temperatures, in harmony with expectation.[17] To confirm that the kinetics found with chlorine were diffusion controlled, a few experiments were made using chlorine dioxide solutions which also reacted with pyrite to give only sulfate. Again the energy of activation, Fig. 4, was 4900 cal per mole and the b factor 1.2. The K_t value for chlorine was 1.85 times the K_t value for chlorine dioxide under identical experimental conditions, which is not an unreasonable value for the ratio of the diffusion coefficients as predicted by Eq. 2.

The present study has been made in some detail to establish a norm for transport control behavior before studying the more complex reactions of other ores, such as galena,[18] where mixed transport and chemical control can occur and elementary sulfur may be found as an oxidation product. The general precision of the present experiments is satisfactory proof of the general adequacy of the apparatus, analysis, and experimental techniques.

It is unfortunate that only sulfate is produced from pyrite with chlorine water. This mineral occurs in nature associated to some degree or other with most other sulfide ores, and its oxidation to sulfate is economically wasteful of oxidant, using up 7½ moles of chlorine for each mole of pyrite attacked.

$$2FeS_2 + 15Cl_2 + 16H_2O = 2Fe^{3+} + 30Cl^- + 32H^+ + 4SO_4^{2-}$$

Acknowledgments

This work was carried out under Grant No. 9535 of Project D.44-95-35-05 from the Defence Research Board of Canada and acknowledgment is gladly made to the Board for permission to publish.

Discussion of this paper sent (2 copies) to AIME by Dec. 1, 1957 will appear in AIME *Transactions* Vol. 212, 1958, and in JOURNAL OF METALS, October 1958.

References

[1] K. W. Downes and R. W. Bruce: *Canadian Mining and Metallurgical Bulletin*, 1955, vol. 48, p. 127.
[2] J. E. Anderson, J. Halpern, and C. S. Samis: *AIME Trans.*, 1953, vol. 197, p. 554; JOURNAL OF METALS, April 1953.
[3] J. F. Stenhouse and W. M. Armstrong: *CIM Trans.*, 1952, vol. 55, p. 46.
[4] F. A. Forward: *CIM Trans.*, 1953, vol. 56, p. 363.
[5] D. P. Seraphim and C. S. Samis. To be published.
[6] G. D. Von Arsdale: *Hydrometallurgy of Base Metals*. McGraw-Hill Book Co. New York, 1953.
[7] A. R. Choppin and I. C. Faulkenberry: *Journal* Amer. Chemical Soc., 1937, vol. 59, p. 2203.
[8] A. Black and J. B. Goodson: *Journal* Amer. Water Works Association, 1952, vol. 44, p. 309.
[9] V. N. Grinevick: *Zhurnal Prikladnoi Khimii*, 1941, vol. 14, p. 63, and 1941, vol. 35, p. 8220.
[10] H. B. Slater: American Patent No. 1,066,855, 1913.
[11] E. Brunner: Austrian Patent No. 171,405, 1952.
[12] M. I. Sherman and J. D. H. Strickland: *AIME Trans.*, 1957, vol. 209, p. 795; JOURNAL OF METALS, June 1957.
[13] M. I. Sherman and J. D. H. Strickland: *Anal. Chem.*, 1955, vol. 27, p. 1778.
[14] C. L. Luke: *Anal. Chem.*, 1949, vol. 21, p. 1369.
[15] D. S. C. Polson and J. D. H. Strickland: *Anal. Chim. Acta.*, 1952, vol. 6, p. 452.
[16] L. L. Bircumshaw and A. C. Riddiford: *Quarterly Reviews*, 1952, vol. 6, No. 2, p. 157.
[17] S. Glasstone, K. J. Laidler, and H. Eyring: *The Theory of Rate Processes*. McGraw-Hill Book Co. New York, 1941.

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AIME NEWS

Banquet to Highlight Steelmaking Meeting

Edward A. Livingstone is to be the featured speaker at the annual fellowship dinner on December 5, one of the highlights of the 15th annual Electric Furnace Steel Conference to be held December 4 through 6, at the Penn-Sheraton Hotel, Pittsburgh.

Mr. Livingstone is vice president, Babcock and Wilcox Co., and heads the Tubular Products Div., Beaver Falls, Pa. Toastmaster for the evening will be Stanley M. Norwood, assistant to the president, Electro Metallurgical Co., Div. of Union Carbide Corp., New York.

The conference will open on Wednesday morning, December 4, with a plant trip to Beaver Falls, Pa., where conferees will inspect the operations there of Babcock and Wilcox Co. Luncheon will be provided by the company and buses will give transportation to and from the Pittsburgh meeting headquarters.

Interesting technical sessions are planned for the next two days of the conference. Some of the subjects to be covered on Thursday, December 5, include nitrogen in electric furnace steel and refractories. There will be an ingot session on vacuum metallurgy covering electric arc furnace practice variables on quality, a castings session on foundry practices, and one on economic utilization of power on Friday, December 6.

The preliminary program for the meeting will appear in JOURNAL OF METALS, November, and the final program in the December conference issue.

New Engineering Center

The architects and consulting engineers for the new United Engineering Center Building have been chosen. The architects are Shreve, Lamb & Harmon Assoc. The mechanical engineers are Jaros, Baum & Bolles; the structural engineers are Seelye Stevenson Value & Knecht. The new center will be located on First Ave. near the U. N. buildings.

The Programs Committee of IMD has announced that programming of research papers based on submission of a 200 to 300-word abstract will be continued at the AIME Annual Meeting in February 1958. Authors should submit their abstracts in three (3) copies prior to Nov. 15, 1957, to:

IMD Programs Committee
The Metallurgical Society of AIME
Room 912
29 West 39th Street
New York 18, N. Y.

The abstracts should not include photographs, graphs, or diagrams.

This is the procedure that was followed for the IMD 1957 Fall Meeting and was discussed fully on p. 651 of the May issue, JOURNAL OF METALS.

High-Temperature Group Plans Symposium For Annual Meeting

The IMD High-Temperature Alloy Committee is planning a symposium on *Processing of High-Temperature Alloys* for the AIME Annual Meeting in February.

The symposium will include contributed papers on the arts and sciences of the melting, casting, working, and heat treating of high-temperature alloys, and the relationship between these processing operations and properties.

The committee wishes to encourage the IMD membership to submit abstracts related to these topics according to the new procedure described in the *Editorial*, JOURNAL OF METALS, May 1957, p. 651. (Send three copies of abstracts, 200 to 300 words, to **IMD Programs Committee, Metallurgical Society of AIME,** 29 W. 39th St., New York 18, N. Y.; *Attention: High-Temperature Alloys Committee.)* Abstracts should be submitted on or before **Nov. 15, 1957.**

(Continued on page 1390)

Prof. Wilson to Talk On Ancient Egypt At Annual IMD Banquet

At the November IMD meeting in Chicago, Professor John A. Wilson will be the speaker at the Fellowship Dinner.

A professor in Egyptology at the University of Chicago, Prof. Wilson will examine those elements of the ancient Egyptian culture which are still influential in contemporary life. Thus, he has titled his talk, *Five Thousand Years of Modern Egypt.* He will also discuss the intellectual achievements and limitations of the Egyptians in relation to their own culture.

In accordance with the changed procedure of presentation of papers detailed in the May issue of JOURNAL OF METALS, five sessions have been scheduled, based on the submission of research abstracts; a total of 48 papers will be presented.

Also experimenting with the new program method will be the Committee on Chemistry and Physics of Metals, which has based its sessions of Monday and Tuesday afternoons on research abstracts. The Monday afternoon session will be on the *Structure of Solid Solutions.* The session on Tuesday afternoon will be on the *Science of Metal Hardening.* Fourteen papers have been scheduled for these two sessions.

Varied Program for Rocky Mt. Conference

At the Rocky Mountain Conference to be held at Denver, from Oct. 30 to Nov. 1, 1957, there will be interesting combination of technical sessions and social events.

Of special interest should be the symposium on metallurgy as well as a panel on uranium mining. A paper by John Q. St. Clair will be presented on channel sampling for uranium.

A trip to Coors Brewery in Golden and a homecoming football game will climax the conference.

ISD Names Director

F. M. Hamilton was recently named by the Iron and Steel Division to be their fourth director to serve on the board of The Metallurgical Society of AIME. Other members previously named were K. L. Fetters, H. B. Emerick, and K. C. McCutcheon. Earlier this year, Mr. Hamilton had been transferred to the Cleveland Works, Jones & Laughlin Steel Corp., as sinter plant superintendent, blast furnace department, from Star Lake, N. Y.

Triangle Cruise Is Planned for the AIME Post-Annual Meeting

For those feeling a need for relaxation after the AIME 1958 Annual Meeting, a cruise aboard the *Queen of Bermuda* has been planned.

The ship will be leaving New York February 21 and will be returning March 1. The boat will stop in Bermuda and Nassau; however, hotel reservations will not be necessary, since time in ports will be sufficient only for shopping and sightseeing.

Those members attending the Annual Meeting who wish to go on the cruise should contact Leon V. Arnold, 33 Washington Square West, New York 11, N. Y., for details. Naturally, early requests will be accorded the choicest available space aboard ship.

High-Temperature

(Continued from page 1389)

If the author wishes his paper to be published, he should submit three copies of the manuscript to the Publication Committee of AIME. Selection of an abstract for presentation at the symposium does not necessarily assure publication of the manuscript in the JOURNAL OF METALS, nor does approval for publication of the manuscript assure presentation of the paper at the High-Temperature Alloy Symposium.

Abstracts for this symposium could be concerned with melting, casting, or powder metallurgical processes; or with the forging, rolling, or extrusion of billets; or with heat treating; and the relationship between these processing operations and mechanical and physical properties. The committee is interested in papers related to both the conventional high-temperature alloys and the newer alloys based on refractory metals, intermetallics, and nonmetallics.

ECPD-EJC Conference

The Engineers' Council for Professional Development will hold its twenty-fifth annual meeting in conjunction with the fourth annual General Assembly of the Engineers Joint Council. This joint program is being held to express the unity and complementary nature of the goals and purposes of ECPD and EJC.

The conference will cover the engineer's position in the armed forces and his position in industrial management. Also evaluated will be the possibilities of a two-year post high school curricula in technological education in the next ten years and post-graduate education for engineers.

The General Assembly will be held at the Statler Hotel in New York on October 24 and 25.

Scott Turner, Mining Engineer, Awarded 1957 Hoover Medal

Scott Turner, former director of the U. S. Bureau of Mines, has been named by four major national engineering organizations to receive their jointly sponsored Hoover Medal for 1957. The award is given "by engineers to a fellow engineer for distinguished public service." It is one of the most distinguished honors bestowed by the profession. The sponsors are ASCE, AIME, ASME, and AIEE.

Presentation of the award will be in New York next February at the AIME Annual Meeting, of which Mr. Hoover was President in 1920 and which Mr. Turner also headed as President.

Born in Lansing, Mich., Mr. Turner received an A.B. in science from the University of Michigan, which later conferred on him the honorary degree of doctor of engineering. He received the degrees of B.S. and E.M. from Michigan College of Mines, which later as the Michigan College of Mining and Technology, awarded him the honorary degree of doctor of engineering. He also holds the honorary degree of doctor of science from Colorado School of Mines and from Kenyon College.

Mr. Turner's career, both as a mining engineer and as the head or member of major government missions, has taken him to many countries, and his achievements in both fields and in education have been hailed on many occasions. He is also the author of some 50 technical papers.

Mr. Turner's early engineering years were occupied with a variety of activities in several Western States and in Alaska and by studies of properties in Northern Africa and parts of Europe.

After World War I, Mr. Turner was technical head of the Mining Corp. of Canada Ltd. and for seven years he helped in the development

and operation of silver and copper mines in the Dominion and properties in other parts of the world. After 17 years in foreign countries, he returned to become director of the USBM under Secretary of Commerce Hoover, continuing when Mr. Hoover became President. Mr. Turner served in Washington nine years. Later, he became associated with various mining activities as executive or consultant.

METAL INDUSTRY MEETINGS

Oct. 7-9, National Electronics Conference, Hotel Sherman, Chicago.

Oct. 7-12, Societe Francaise de Metallurgie, fall meeting, Paris, France.

Oct. 9-11, Symposium on Vacuum Technology, Hotel Somerset, Boston.

Oct. 15-17, Corrosion Convention and Exhibition, Central Hall, Westminster, and the Royal Horticultural Society's Old Hall, London, England.

Oct. 16-19, Pacific Coast Convention, American Ceramic Soc., Northern California Section, Sheraton-Palace Hotel, San Francisco.

Oct. 17-18, Magnesium Assn., annual convention, Biltmore Hotel, New York.

Oct. 28-31, American Nuclear Soc., Henry Hudson Hotel, New York.

December 1957, Indian Inst. of Metals, 11th annual technical session, Bombay, India.

Dec. 1-6, ASME annual meeting, Hotels Statler and Sheraton-McAlpin, New York.

Dec. 8-11, American Inst. of Chemical Engineers, annual meeting, Conrad Hilton Hotel, Chicago.

News of EDUCATION

► U. S. Steel Foundation Inc., has announced a program of aid-to-education with grants payable in 1957 totaling nearly $1.8 million to over 600 of the Nation's privately-supported liberal arts colleges, universities, technological institutes, and medical schools.

In making the announcement, Roger M. Blough, chairman of the board of trustees of the Foundation said: "The action of the Trustees represents an effort by this Foundation to extend aid in some form to almost every voluntarily supported institution of higher learning which has clearly demonstrated both its desire and ability to help itself through the crisis presently facing higher education."

The Foundation's seven-part program embraces the following:

Accredited Liberal Arts Colleges —$500,000. Unrestricted operating aid to all the 430 accredited four-year member colleges of all the state, regional, and national college fund-raising groups. Similar aid direct to 70 other selected institutions unaffiliated with those groups.

Nonregionally Accredited Liberal Arts Colleges—$100,000. Operational and capital-aid grants, to be administered through the Assn. of American Colleges, to a number of colleges not yet fully accredited, but seeking to provide greater community service.

Universities and Engineering Institutes—$110,000. Operational aid of an unrestricted character for 55 major private universities and engineering schools throughout the nation.

Medical Schools and Medical Teaching—$190,000. Operational assistance of $65,000 for all 82 medical schools and the balance for two capital-facility grants for medical teaching centers to enhance and strengthen their programs.

Postgraduate-Study Fellowships—$150,000. Continuation and expansion of the Foundation's present doctoral-level graduate-study program covering the humanities, social sciences, biological and physical sciences, and engineering, with grants and allotments equally divided between public and private institutions.

(Continued on page 1392)

IMD Committee Plans Annual Meeting Talks On Impulsive Loading

The IMD Physics and Chemistry of Metals Committee has arranged a one-day symposium on *Impulsive Loading* for the AIME Annual Meeting in February in New York. The symposium will consist of three lectures by invited speakers in the morning and short (10-min) contributed papers in the afternoon.

The three invited lectures will be given by outstanding workers in the field of high-speed stressing. Loading times from milliseconds down to microseconds and shorter will be considered. The metallurgical and physical points of view will be emphasized rather than the mechanical. It is hoped that the talks will stimulate active discussion from the floor.

Interested persons are invited and encouraged to submit abstracts of papers that they wish to present at the afternoon session. These papers should relate to current work which may have recently been completed or may be in progress.

Vital information concerning the submission of abstracts is as follows:

Subject: *Impulsive Loading*
Length: 200 to 300 words (no photographs, diagrams, or tables should be used).
Copies: Send 3, marked *Impulsive Loading Session.*
Deadline: Nov. 15, 1957
Send to: IMD Programs Committee
Metallurgical Society of AIME
29 West 39th Street
New York 18, N. Y.

Some topics that could be discussed are delayed yielding, shock-wave phenomena, dislocations at high speeds, strain-rate effects at high strain-rates, and fracture phenomena.

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AROUND THE SECTIONS

• The **Buffalo NOHC Section** will hold its eighth annual meeting, Nov. 12, 1957, at the Royal Connaught Hotel, Hamilton, Ont., Canada.

The morning will be devoted to an inspection trip to the Steel Co. of Canada, No. 2 open hearth shop. This shop has been selected, since it best depicts average conditions of other shops in the district.

The meeting will be conducted under the direction of Section Chairman John R. Atkinson, Dominion Foundries and Steel Corp., Buffalo.

The afternoon technical session, under the direction of Technical Program Chairman C. E. Moyer and Assistant Chairman John E. Hood, will start with a presentation of the U. S. Steel Corp. film, *The Germ*, relating to production and quality control, followed by a floor discussion of the features covered by the film. Discussions on pouring practice, checker cleaning, and elimination of bottom delays will follow.

The Open-Hearth Suppliers' Committee will provide the luncheon and the before-dinner cocktail party. The customary annual dinner will wind up the meeting.

Advance registration facilities will be provided in the evening, Monday, November 11. Parties desiring to be placed on the mailing list should contact Harry A. Morlock, Secretary, 937 Rand Building, Buffalo 3, N. Y.

• This year the **Southwestern NOHC Section** will celebrate its 20th anniversary during the annual Globe Trotter's meeting on October 3 and 4, at the Shamrock Hilton Hotel, Houston. Host for the meeting will be the Sheffield Steel Div., Armco Steel Corp.

Arrangements have been made for special cars on the Missouri Pacific's Texas Eagle to leave St. Louis the evening of October 2 and arrive in Houston the following morning. The return trip will leave Sunday morning, October 6. Reservations should be made immediately through the Section.

Plans for Thursday include a tour of the Sheffield Plant in the morning and luncheon there. Registration will take place in the late afternoon. On Friday, there will be technical sessions in the morning and afternoon. For the ladies there will be a special luncheon and style show at the Shamrock Hilton Hotel as guests of Sheffield Steel. In the evening transportation will be provided to the San Jacinto Inn where there will be a cocktail party and the Fellowship Dinner.

There will be seven subjects discussed at the technical sessions: *Heating up Open Hearth Furnaces with Natural Gas*, George Grosvenor, Colorado Fuel & Iron Corp.; *Basic Electric Furnace Operations vs Open Hearth Operations*, David L. McBride, U. S. Steel Corp. and Bill Steinheider, Sheffield Steel; *Review of Uses of Oxygen in Steelmaking*, Gene Miller, Colorado Fuel & Iron Corp.; *Recent Developments in Iron and Steelmaking*, C. H. Taylor, Research Div., Armco Steel Corp.; *Pouring Pit Practices and Their Effects on Soundness and Surface Quality*, W. F. Mott, Sheffield Steel; *High Pressure Gas vs Steam and Oil*, Arthur L. Howard, Granite City Steel Co., Daniel J. Murphy, Jr., Scullin Steel Co., and Stephen M. Purcell, Lone Star Steel Co.; and *Questionnaire on Open Hearth Brick Consumption*, A. H. Sommer, Keystone Steel & Wire Co.

• The **Western NOHC Section** met on September 17 at the Rodger Young Auditorium, Los Angeles, for dinner. Speaker of the evening was G. M. Prioli, engineer, Electric Furnace Dept., Bethlehem Pacific Coast Steel Co., Los Angeles. He discussed the *Effects of Tap Voltages on Electric Furnace Operation*.

Officers of the Section for the year 1957-1958 are: William F. Bowers, Jr., Kaiser Steel Corp., executive chairman; J. L. Venturini, Bethlehem Pacific Coast Steel Co., vice chairman; and Bruce J. Paulsen, Missouri Refractories Co., secretary-treasurer. Directors who will serve a one-year term are: Robert Prout, Columbia-Geneva Steel Div., U. S. Steel Corp.; Jack Fuqua, Stanley Foundries; Jack Fahey, American Manganese Steel Co.; Lloyd Paulsen, Gladding, McBean and Co.; and Carl Wissman, Pacific Southern Foundries.

• First fall meeting of the **Connecticut Section** was a combined plant visit-dinner-technical session. The day's proceedings started with a trip to Fafnir Bearing Co., Newington, Conn. Dinner was held at the Indian Hill Country Club, Newington, and Henry Hubbell, chief metallurgist, Fafnir Bearing Co., was the guest speaker. He discussed *Special Materials and Their Selection for Bearing Applications*.

• *Rare Earths and Thorium* was the topic of discussion at a joint meeting of the **St. Louis Section** and the Inorganic Div., American Chemical Soc., on September 13 at the Hotel York, St. Louis. Howard E. Kremers, technical assistant to the president, Lindsay Chemical Co., presented a comprehensive survey of the occurrence of rare earths and thorium ores, their industrial processing and process chemistry, and recent developments in the growth of the industry.

• W. R. Paxton presented a *Brief Case for Business* at the September 4 meeting of the **San Francisco Section** at the Engineer's Club, San Francisco. The program was provided by Standard Oil Co. of California. Second topic for the evening was *Weather*, presented by a sound and color film which illustrated the origin, development, and consequences of weather. Dinner preceded the technical session.

This New World of Metals **is a 16-mm sound color film which runs 20 min, available free except for shipping expenses, from the Motion Picture Dept., Westinghouse Electric Corp., 3 Gateway Center, Pittsburgh 30, Pa. America's very survival might well depend upon our developments in the field of metallurgy, where metals are being subjected to rigid conditions such as the tremendous stress and skin temperature of today's high flying jet planes. This interesting film is a guide through one of America's newest pilot production facilities for the research, development, and processing of new metals and alloys.**

Applications of R.F. Induction Heating **is a new 16-mm sound color film which runs 15 min, available free except for shipping charges, from the Motion Picture Dept., Westinghouse Electric Corp., 3 Gateway Center, Pittsburgh 30, Pa. This factual film shows the advantages and the success of RF heating when this process is used to through-heat, harden, anneal, solder, or braze metals. In actual operations, you see the varied applications of RF heating for the manufacture of metal parts and assemblies. Case histories are presented showing advantages and economies for heat-treating metals.**

Education

(*Continued from page 1391*)

Project Grants in Aid of Education—$70,000. Previous project grants were continued and new ones were added, including provision for the Commission on Colleges and Industry of the Assn. of American Colleges, the Council for Financial Aid to Education, the Institute for International Education, the Assn. of College and Reference Libraries, and a project for stimulation of alumni giving.

Major Capital Grants. Authorization of $665,000 for payment in 1957 and, additionally, commitments of $525,000 payable in later years, for endowment, building, equipment, and other facility needs of 16 outstanding universities, liberal arts colleges, women's colleges, engineering schools, and other institutions.

PERSONALS

Marshall Sittig, president and managing director of the American Lithium Inst. Inc., has been appointed chairman of a symposium on alkali metals to be held at the 133rd National Meeting of the American Chem. Soc. slated for San Francisco in April 1958.

Bradley B. Evans announced his retirement as president of the Alloy Casting Inst. at the Institute's twenty-fifth annual meeting. He shall be succeeded by **F. M. Fahrenwald,** president and chairman of the board of the Fahralloy Co., Harvey, Ill. **Paul L. McCulloch, Jr.,** president of the Electro-Alloys Div., American Brake Shoe Co., Elyria, Ohio, was elected vice president. **E. A. Schoefer,** Mineola, N. Y., was re-elected executive vice president and treasurer of the Institute. Two new members, **Frank Kiper,** president of Michigan-Standard Alloy Casting Co., Detroit, and J. B. Dear, sales manager, the Duraloy Co., Scottsdale, Pa., were named to the Institute's board of directors. Of special interest to those attending the meeting was a report given by **P. R. Gouwens,** chairman of the ACI Technical Research Committee.

H. P. Hughes, formerly technical consultant for the Union Carbide Ltd., in London, has left to take a position in Scotland.

William A. Steel, vice president in charge of operations, has been promoted to executive vice president of Wheeling Steel Corp. **Paul W. Koenemund** will succeed him as vice president in charge of operations.

John C. McDonald, assistant technical director of the Dow Chemical Co.'s magnesium department, received the annual Willard H. Dow Memorial Award for research in magnesium.

Charles L. Schmidt has been promoted from assistant to full technical director of the Titanium Div., National Lead Co.

John M. Ohno has left the Kaiser Steel Corp. to take a position with the research laboratories at Allis-Chalmers Manufacturing Co., Milwaukee.

Roy Dahlstrom has been appointed director of research of National Lead Co. He was formerly technical director of the Titanium Div.

J. B. Dempsey has been named a vice president of the Speedway Manufacturing Div. of the Thor Power Tool Co., Chicago.

Thomas M. Kaneko is no longer with Union Carbide Nuclear Co., but is now associated with the U. S. Industrial Chemicals Co., Cincinnati.

J. M. Gaines has been appointed associate technical director of the Linde Co.; he was formerly director of research.

Herbert H. Johnson, Jr., has left the department of metallurgical engineering at Case Institute of Technology and is now with the department of metallurgy at Lehigh University, Bethlehem.

James H. Jacobs has moved from the Ohio office of Electro Metallurgical Co., to its office in Niagara Falls, N. Y.

E. V. Peterson is no longer with the DuPont Co. at Dana, Ind., but is now research metallurgist with DuPont experimental Station in Wilmington, Del.

Reinhard P. Abendroth has been assigned to the Minerals and Chemicals Engineering Group at Electro Metallurgical Co. He had held previous positions at the Eberhard Manufacturing Co. and at the Los Alamos Scientific Laboratory. **Edward L. Harmon,** previously a research assistant at Case Institute of Technology, has been assigned to the Metals Research Group.

Robert B. Steck is now associated with the Titonium Metals Corp. of America as a development engineer, in Las Vegas, Nev.

H. L. Talbot, consulting metallurgical engineer, has changed his office address to Room 911, 209 Washington St., Boston 8, Mass.

Thomas H. Wickenden, retired vice president of The International Nickel Co. Inc., was honored by Denison University. He was given the degree of doctor of science.

M. Robert Herman, assistant to the vice president in charge of American Smelting & Refining Co.'s Federated Metals Div., named vice president of the newly acquired Enthone Inc. subsidiary. **G. M. Bauman,** former assistant to the vice president in charge of the Federated Metals Div., will now head the new Central Aluminum Dept. with the title of General Manager.

Wylie J. Childs has resigned as professor of metallurgical engineering and department head at Lafayette College to accept a post as associate professor, Renssalaer Polytechnic Institute, Troy, N. Y.

A. L. Lind has been appointed chief draftsman, Rolling Mill Div., E. W. Bliss Co. He had been project engineer at the division.

Wilmer Witt has transferred from Bishop, Calif., to the Uravan, Colo., office of Union Carbide Nuclear Corp.

James L. Shore has become research metallurgist, Climax Molybdenum Co., Climax, Colo.

Jan A. Vermeulen has retired from the Mining Equipment Corp., New York.

Craig G. Kirkpatrick, formerly with Collins Radio Co., Burbank, Calif., has accepted a position as metallurgist with Research Chemicals Inc. in the same city.

Upendra N. Bhrany has joined Brunswick Mining & Smelting Corp., Ltd., Bathurst, Canada. He had formerly been associated with Columbia University School of Mines, New York.

William P. Roe, formerly with the Southern Research Inst., Birmingham, has joined American Smelting & Refining Co.'s Central Research Laboratory, S. Plainfield, N. J.

Frank Jacobs, Jr., has accepted the position of senior engineering supervisor, Metallics Materials Section, Lemco Aircraft Corp., Garland, Texas. He was formerly associated with Boeing Aircraft Co. as lead engineer in charge of the metallurgical laboratory.

William A. Anderson has been promoted to assistant chief of the Physical Metallurgy Div., Alcoa Research Laboratories. He has been employed at the laboratories since receiving his doctorate degree from Carnegie Institute of Technology in 1943.

Richard W. French, Jr., has been elected president of United Carbon Corp. He previously has been vice president in charge of production for Standard Oil Co. of Ohio.

Several changes in the board and officers have been made in the Atlas Powder Co. of Wilmington, Del. Directors of the company elected **D. J. Carroll Copps** as senior vice president and **John H. Leary,** formally assistant to the financial vice president, was appointed assistant to the president.

Robert C. Bertossa, research metallurgist, Stanford Research Inst., Menlo Park, Calif., spoke at the San Francisco meeting of ASME in June on vacuum metallurgy.

Charles D. Preusch, formerly foundry metallurgist, Spaulding Works, has been named chief metallurgist at the works, Crucible Steel Co., Harrison, N. J.

Francis B. Foley, consulting metallurgist to International Nickel Co., has accepted an appointment as executive metallurgical engineer with the Pencoyd Steel & Forge Corp., Philadelphia.

Lawrence S. Darken has been appointed associate director of U. S. Steel Corp.'s Fundamental Research

Laboratory, Monroeville, Pa. He was previously assistant director of physical chemistry with the Laboratory. After spending several years in engineering and metallurgical work in Utah and California, **Charles A. Mueller** is returning to the Lindberg Engineering Co., Chicago, as chief engineer of the new Gas Process Div.

H. Edward Fuhrmeister, formerly with the Allegheny Ludlum Steel Corp., Brackenridge, Pa., is now with Titanium Metals Corp. of America, Toronto, Ohio.

William H. Miller, having recently graduated from college, is now working for American Smelting & Refining Co., Corpus Christi, Texas.

Milton F. Meissner, an industrial consultant and former vice president of Olin Mathieson Chemical Corp., has been elected a director of Consolidated Diesel Electric Corp., Stamford, Conn.

Frank W. Glaser, executive vice president of Cleveland's Alloy Precision Castings Co., has also been appointed vice president of Mercast Corp., New York, the parent company.

E. W. Engle has left Vascoloy-Ramet Corp., Waukegan, Ill. and is now at Kennametal Inc., Latrobe, Pa.

Previously associated with Sylvania Electric Products Inc., Hicksville, N. Y., **Norman P. Pinto** is presently with the Beryllium Corp., Reading, Pa.

Edward L. Harmon, Jr., formerly with Case Institute of Technology, is now working at the Metals Research Laboratories, Electro Metallurgical Co., Niagara Falls, N. Y.

Charles W. Haynes has been named associate professor and head of the Metallurgical Engineering Dept. at Montana School of Mines. He had been a senior research engineer for Autonetics Corp., Downey, Calif.

Stanley M. Norwood has been appointed assistant to the president of Electro Metallurgical Co. He will continue as vice president of this division of Union Carbide Corp.

Materials Research Corp., Yonkers, N. Y., has appointed **Sheldon Weinig** as president. He is a former assist-

New Project Offers Tips for Job Seekers; Gives Hints on Writing Resumes

Sample Resume

After a survey proved the inadequacy of 62 pct of personal resumes for technical and professional positions, Orville E. Armstrong & Co. is offering information on *How to Write Your Resume*. See the sample given above.

A resume should cover experience, education, and personal information of direct interest to a potential employer. The brief summary of background must contain a condensation of your entire experience record, accentuating those areas which are directly related to the new position. Vital is the positive statement concerning job objective, pinpointing the resume to a particular job rather than for any opening available.

The booklet emphasizes the importance of omitting information which is not of specific interest to your future employer, as well as personal opinions which are not a part of your employment history or personal background. Also stressed is quality; since the resume arrives first, it must represent you, the writer, in appearance, and speak in your behalf. Spacing and paragraphing must be adequate, and of course, the material should be typed on good quality rag bond paper of standard size—8½x11 in. Resumes and cover letters should be reproduced by a precise offset method in standard typeface.

Although a one-page resume is suggested for lower bracket jobs, this is not a blanket rule for other types of positions. Particularly on management and technical occupational levels, sound judgment as to length of an effective resume must apply.

ant professor of metallurgy at New York University.

Clyde Wyman has left Vulcan Steel Foundry Co., Oakland, Calif., and is now associated with the L. F. M. Co. in Atchison, Kan.

Ralph W. Getz has joined the staff of Battelle Memorial Institute in Columbus, Ohio.

D. G. Treilhard has accepted a position as assistant superintendent (relieving) in Broken Hill, No. Rhodesia with the Rhodesia Broken Hill Development Co. Ltd.

At its last regular meeting, the board of directors of the Ajax Electrothermic Corp. appointed **A. Dean Meyer** general manager. Mr. Meyer was recently elected director and is also a vice president.

Robert L. Reed has been appointed regional manager of the Pittsburgh sales region for Electro Metallurgical Co. Prior to his new appointment he was acting regional manager.

Julian H. Cherubini from Massachusetts Institute of Technology has recently been appointed to the staff of the Metallurgy Div., Oak Ridge National Laboratory, Oak Ridge, Tenn.

The National Bearing Div. of American Brake Shoe Co. has appointed **Paul J. Bauman** and **Albert L. Hunt** as vice presidents. Mr. Bauman was formerly general manager of National Bearing's plant in Meadville, Pa.

William G. Pfann, Metallurgical Research Dept., Bell Telephone Laboratories, Murray Hill, N. J., has been awarded the Francis J. Clamer Medal of The Franklin Institute in "recognition of his discovery and application of zone refining to metals and other crystalline substances." Presentation was made at the Institute's annual Medal Day, October 16.

Oliver C. Ralston, chief metallurgist, U. S. Bureau of Mines, is retiring from Government service. He was chairman of EMD in 1951.

A. E. Nehrenberg, supervisor of tool and die steels and welding, has been succeeded as acting supervisor of constructional alloy steels by **Robert W. Lindsay,** who has joined the staff of Crucible Steel Co. of America, Pittsburgh, central research laboratory. **John H. Hoke** has been appointed supervisor of the stainless steels section of the central research laboratory of Crucible Steel.

OBITUARIES

Clayton Ruel Genung (Member 1953) died recently. Born in 1898 at Corning, N. Y., Mr. Genung attended the University of Chattanooga in Tennessee. He had worked for the Southern Chemical Cotton Co., Chattanooga, Tenn.; Buckeye Cotton Oil Co., Memphis, Tenn.; and his last position was with Ross Meehan Foundries, Chattanooga, Tenn.

Arthur W. Gray (Member 1918) died on Apr. 6, 1957. Born in Brooklyn, N. Y., in 1875, he graduated from the University of California and received his Ph.D. from the University of Berlin, Germany. Mr. Gray had held various teaching positions and fellowships and had done most of his work in the fields of physics and metallurgy.

R. S. Sherwin, Sr. (Member 1949), died on July 2 at the age of 80. He had been living in Corpus Christi, Texas. Born in Waseca, Minn., he graduated with a degree in chemistry from the University of Oklahoma. Mr. Sherwin spent 35 years with the Aluminum Co. of America, working on alumina process control and development. In 1940, he joined the Reynolds Metals Co. where he later became a vice president. In his memory, Reynolds Metal Co. has renamed the alumina plant operated in Corpus Christi.

NECROLOGY

Date Elected	Name	Date of Death
1936	Algernon N. Borszich	Unknown
1921	Philip B. Bucky	Aug. 8, 1957
1902	H. E. Crawford Legion of Honor	Sept. 23, 1952
1953	Clayton R. Genung	Sept. 25, 1955
1918	Arthur W. Gray	Apr. 6, 1957
1921	William Hart	December 1956
1903	Charles K. Leith Legion of Honor	Unknown
1902	Lesley McCreath	Aug. 18, 1957
1952	Melvin H. Ott	February 1956
1939	Edward L. Ralston	July 2, 1957
1943	James R. Russell	Aug. 5, 1957
1949	R. S. Sherwin	July 2, 1957
1945	Eugene Staritzky	May 15, 1957
1899	J. B. Tyrrell	Aug. 26, 1957
1949	George A. White	May 5, 1956
1920	George F. Zoffman	June 5, 1957

MEMBERSHIP

Proposed for Membership
Metallurgical Society of AIME

Total AIME membership on Aug. 31, 1957, was 28,134; in addition 3,143 Student Members were enrolled.

ADMISSIONS COMMITTEE

Harold K. Work, Chairman; Francis B. Foley; T. D. Jones; E. S. Machlin; J. H. Scaff; Paul Von Stein; T. H. Winkler.

The Institute desires to extend its privileges to every person to whom it can be of service, but does not desire as members persons who are unqualified. Institute members are urged to review this list as soon as possible and immediately to inform the Secretary's office if names of people are found who are known to be unqualified for AIME membership.

Members

Harold Bernstein, Silver Spring, Md.
Bjorn Edwin, Hallstahammar, Sweden
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COMING EVENTS

Oct. 11, AIME, NOHC Eastern Local Section technical meeting, Sheraton Hotel, Philadelphia.

Oct. 11-12, AIME Niagara Frontier Section, meeting and football game, Cornell University, Ithaca, N. Y.

Oct. 16, AIME New York Local Section, Physical Metallurgy Group, plant trip, IBM, Poughkeepsie, N. Y.

Oct. 18-19, AIME, NOHC Southern Ohio Local Section, annual meeting, Deshler-Hilton Hotel, Columbus, Ohio.

Oct. 30-Nov. 1, AIME Rocky Mountain Minerals Conference, Denver.

Nov. 1, AIME, NOHC Pittsburgh Section, AIME Pittsburgh Section, Engineers' Soc. of Western Pennsylvania, annual Off-the-Record Meeting, Penn-Sheraton Hotel, Pittsburgh.

Nov. 2-8, Second World Metallurgical Congress, Sherman Hotel, Chicago.

Nov. 3-7, AIME, IMD Fall Meeting Morrison Hotel, Chicago.

Nov. 5, AIME, Iron and Steel Division, Technical Sessions, Morrison Hotel, Chicago.

Nov. 12, AIME, NOHC Buffalo Local Section, annual meeting, Royal Connaught Hotel, Hamilton, Ont., Canada.

Nov. 18-21, Conference on Magnetism and Magnetic Materials. Sponsors: AIEE in cooperation with AIME, American Physical Soc., IRE, ONR. Hotel Sheraton-Park, Washington, D. C.

Nov. 20, AIME Niagara Frontier Section, annual Frank J. Tone Award Meeting, Buffalo.

Nov. 21, AIME Utah Section, panel discussion: *Mining Industry: New Methods, Machines, and Materials.* Moderator, N. L. Weiss; panel, J. D. Moore, J. Rosenblatt, P. K. Richardson, H. Mathews.

Nov. 26, AIME Connecticut Section, student night, speaker: K. H. Mair, University of Rhode Island; subject: *Problems in Nuclear Metallurgy;* Town House, New Haven, Conn.

Dec. 4-6, AIME, 15th Electric Furnace Steel Conference, Penn-Sheraton Hotel, Pittsburgh.

Feb. 16-20, 1958, AIME Annual Meeting, Statler and Sheraton-McAlpin Hotels, New York.

Mar. 17-21, EJC Nuclear Congress, International Amphitheatre, Chicago.

Apr. 14-16, AIME, 41st National Open Hearth Steel and Blast Furnace, Coke Oven, and Raw Materials Conference, Hotel Statler, Cleveland.

May 5-6, AIME, Conference on Properties of High-Strength Steel, Penn-Sheraton Hotel, Pittsburgh.

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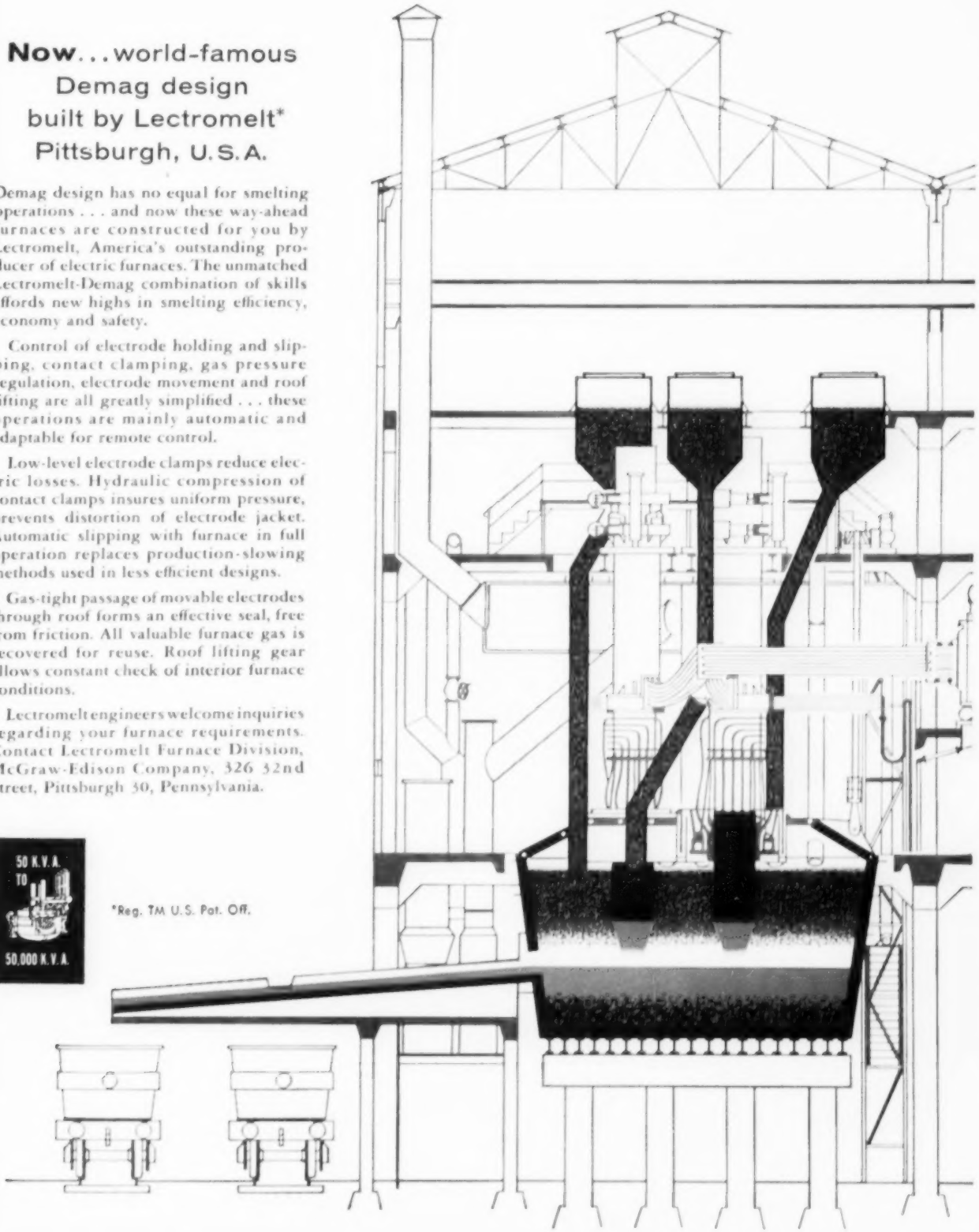

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